

IT AIN'T WHAT YOU DO IT'S THE WAY THAT YOU DO I.T. - INVESTIGATING THE PRODUCTIVITY MIRACLE USING THE OVERSEAS ACTIVITIES OF U.S. MULTINATIONALS

Nick Bloom¹, Raffaella Sadun² and John Van Reenen²

¹ *Dept. Economics, Stanford & Centre for Economic Performance, London School of Economics*

² *Dept. Economics & Centre for Economic Performance, London School of Economics*

March 2006

Preliminary and Incomplete – Comments welcome

Abstract

Productivity growth in sectors that intensively use information technologies (IT) appears to have accelerated much faster in the US than in Europe since 1995, leading to the US “productivity miracle”. If this was partly due to the superior management/organization of US firms (rather than simply the US geographical or regulatory environment) we would expect to see a stronger association of productivity with IT for US multinationals located in Europe than for other firms. We examine a large panel of UK establishments and provide evidence that US owned establishments have a significantly higher productivity of IT capital than either non-US multinationals or domestically owned establishments. Indeed, the differential effect of IT appears to account for almost all the difference in total factor productivity between US-owned and all other establishments. This finding holds in the cross section, when including fixed effects and even when we examine a sample of establishments taken over by US multinationals (relative to takeovers by other multinationals and by domestic firms). We find that the US multinational effect on IT is particularly strong in the sectors that intensively use information technologies (such as retail and wholesale): the very same industries that accounted for the US-European productivity growth differential since the mid 1990s.

Key words: *Productivity, IT, multinationals, organization.*

JEL classification: *E22, O3, O47, O52*

Acknowledgments

We would like to thank Tony Clayton for support and helpful discussions and Mary O’ Mahoney for providing the NIESR Industry data. We would like to thank the Department of Trade and Industry and the Economic and Social Research Council for financial support. Helpful comments have been given by Tim Bresnahan, Eric Brynjolfsson, Paul David, John Haltiwanger, Rupert Harrison, Jonathan Haskel, Dale Jorgensen, Nick Oulton, Mark Schankerman and Paul Seabright and participants at a range of seminars.

This work contains statistical data from the Office of National Statistics (ONS) which is Crown copyright and reproduced with the permission of the controller of HMSO and Queens Printer for Scotland. The use of the ONS statistical data in this work does not imply the endorsement of the ONS in relation to the interpretation or analysis of the statistical data.

I. INTRODUCTION

One of the most startling economic facts of the last decade has been the reversal in the long-standing catch-up of European countries' productivity with the US. Labour productivity growth in the US accelerated after 1995 following a long-term slowdown after the 1970s Oil shocks. Decompositions of this productivity growth show that the great majority has occurred in those sectors that either intensively use or produce IT (information technologies)¹. EU countries had similar productivity acceleration in IT producing sectors but failed to achieve the spectacular levels of productivity growth in the sectors that *used* IT intensively (e.g. O'Mahony and Van Ark, 2003). These sectors include retail, wholesale and financial intermediation. Britain has done better than France or Germany in this respect, but not as well as the US (e.g. Basu et al, 2003). Given the common availability of IT throughout the world at broadly similar prices, it is a major puzzle to explain why these IT related productivity effects have not been more widespread.

So why has there not been faster productivity growth in Europe since the mid 1990s? One explanation is simply differences in the way we measure productivity across countries (Blanchard, 2004). This is possible, but the careful work of O'Mahony and Van Ark (2003) and others who focus on the same sectors in the US and EU, use US style adjustments for hedonic prices, software capitalization and aggregate demand conditions, still find a difference. If the difference is real, then at least two explanations are possible. First, there are some "natural advantages" to the environment in which US plants operate that enables them to take better advantage of the opportunity of rapidly falling IT prices. These natural advantages could be tougher product market competition, lower regulation in the product and labour markets, better access to risk capital, more educated workers, a larger size of market, more geographical space or a host of other factors. A second class of explanations stresses that it is not the US environment *per se* that matters but rather the internal organization (the depth of "organizational capital") of US firms that has enabled better exploitation of IT. For example, US firms may be simply better managed or they have adopted features that are better at exploiting IT (e.g. more decentralization or flatter hierarchies)².

¹ See, for example, Stiroh (2002a). Jorgenson (2001), Oliner and Sichel (2001). In the 2002-2004 period Oliner and Sichel (2004) find that the US productivity growth remained strong, but there was a more widespread increase in productivity growth across sectors.

² Bresnahan, Brynjolfsson and Hitt (2002) and Caroli and Van Reenen (2001) both find that internal organisation and other complementary factors such as skills are important in generating significant returns to ICT.

One way to test between the “US environment” and the “US organization” hypotheses is to examine the IT performance of US owned organizations in a non-US environment. Assuming that US multinationals export their business models outside the US – and a walk into McDonalds or Starbucks anywhere in Europe suggests that this is not an entirely unreasonable assumption – then analyzing the IT performance of US multinational establishments in Europe should be informative. (We return to the origins of differences in European vs. US organizational forms in the conclusion).

In this paper we examine the productivity of IT in a panel of establishments located in the UK, examining the differences in IT intensity and productivity between plants owned by US multinationals, plants owned by non-US multinationals and domestically owned plants. The UK poses a useful testing ground because (a) it has not experienced a US-style productivity acceleration since 1995 (as Basu et al (2003) show) and (b) it is a large recipient of foreign direct investment so we are able to compare across many types of ownership. A key comparison group for US multinationals are “statistically similar” non-US multinationals (i.e. establishments in the same industry, of a similar age, size and factor intensity). We report evidence that the key difference in understanding productivity differences is the ability of US multinationals to gain a higher return to IT than non-US multinationals (and domestic plants). This effect is strongest in precisely those industries that experienced the largest relative productivity gains in the US after 1995 (the sectors that intensively used IT). This finding is robust to a number of tests for omitted variables, the possible endogeneity of IT, and US firms’ “cherry picking” UK plants (we look before and after US takeovers compared to non-US takeovers). In short, we conclude that the higher productivity of IT in the US is not just the US environment, but also has something to do with the internal organization of US firms.

Some preliminary evidence on the importance of different internal organization of US firms can be seen in Figures 1 and 2. This uses data on the internal organizational of over 700 firms in the US and Europe. Figure 1a shows that, on average, firms operating in the US are more decentralized than those operating in Europe³. In Figure 1b, we break down the latter into purely Domestic

³ Decentralization was measured in the same way as Bresnahan et al (2002) using questions related to task allocation and pace setting in order to indicate the degree of employee autonomy. See notes to the Figures for details.

European firms, subsidiaries of European multinationals and subsidiaries of US multinationals. Interestingly, the degree of decentralization of US multinational subsidiaries in Europe is similar to US firms as a whole and is significantly higher than the degree of decentralization of European multinationals (and domestic European firms). In Figure 2 we use a composite measure of management best practices (see Bloom and Van Reenen, 2005, for details). A similar picture emerges – management quality is higher in the US and higher for US multinational subsidiaries in Europe than European subsidiaries.

Our paper relates to several literatures. First, there is a large literature on the impact of IT on productivity, but most of this is based on data aggregated to the industry or macro-economic level. Even the pioneering work of Brynjolfsson⁴ and his co-authors focuses at the firm level which may conceal much heterogeneity between plants *within* firms. In this paper we provide, for the first time, estimates for the level and the returns to IT capital stocks for a panel of around 11,000 establishments, probably the largest micro-based sample in the world for this kind of exercise. Our database, unlike the US LRD, also covers the non-manufacturing sector, which is important as the majority of sectors that use IT intensively are in services.

Second, in a reversal of the Solow Paradox, the firm level productivity literature has found returns to IT that are *larger* than one would expect under the standard growth accounting assumptions. Brynjolfsson and Hitt (2003) argue that this is due to complementary investments in “organizational capital” that are reflected in the coefficients on IT capital. Almost all of these studies are on US firms, however, and the data used is generally prior to the post 1995 acceleration in productivity growth. Examining UK firms that may have made fewer complementary investments we might expect to see lower returns (Basu et al, 2003).

Thirdly, there is a literature on the productivity of multinationals compared to similar non-multinational establishments. The first wave of research that compared domestically owned plants with multinationals was clearly misleading as multinationals are a self-selected group that have some additional efficiency as signaled by their ability to operate overseas. But comparing across

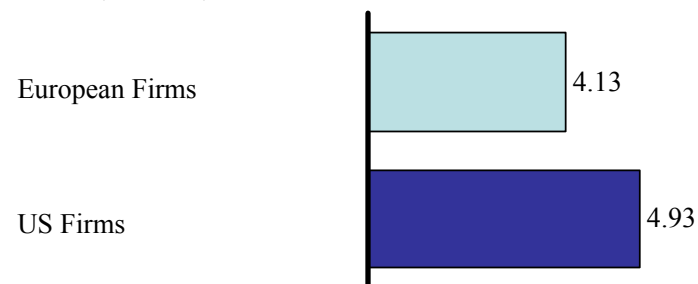
⁴ Brynjolfsson and Hitt (1995, 2003), Bresnahan, Brynjolfsson and Hitt (2002), Brynjolfsson, Hitt and Yang (2002). Brynjolfsson and Yang (1996) or Stiroh (2002b) survey the evidence.

different multinationals it appears that US plants are more productive whether based geographically in the US (Doms and Jensen, 1998) or in other parts of the world such as the UK (e.g. Criscuolo and Martin, 2005). Our paper suggests that a major reason for this is the way in which US multinationals are able to use new technologies more effectively than other multinationals.

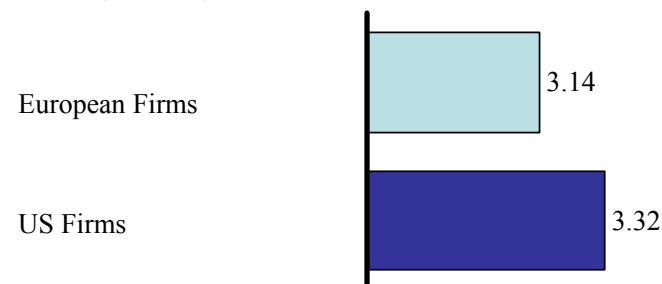
In summary, we do find significant impacts of IT on productivity. We also find that we can account for almost all of the higher productivity of US multinationals by the higher productivity impact of their use of IT. Furthermore, this US advantage is strongest in the sectors that intensively use IT: precisely those sectors that account for the faster productivity growth in the US than Europe since 1995. This suggests that at least some of the differential performance of productivity between the US and the EU since the mid 1990s is due to the internal organization of US firms. Drawing on some of our other work we show that there is evidence for significant differences in the “organizational capital” of US firms relative to British and other European firms, even when these US firms operate in Europe.

The structure of this paper is as follows. Section II discusses the econometric strategy and section III the data. Section IV gives the main results, Section V some interpretation and section VI offers some conclusions.

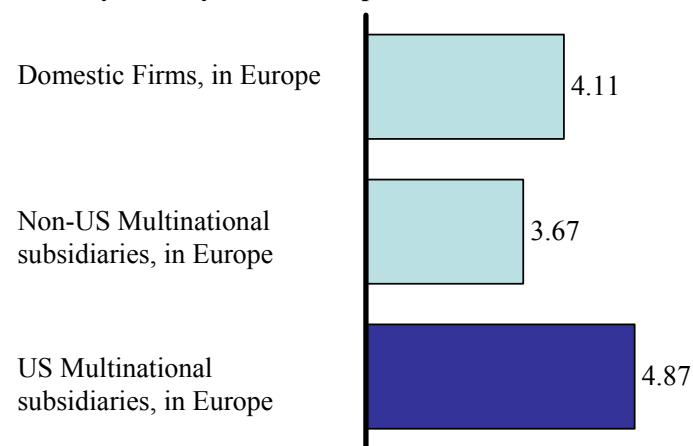
**Figure 1a: Organizational devolvment,
firms by country of location**



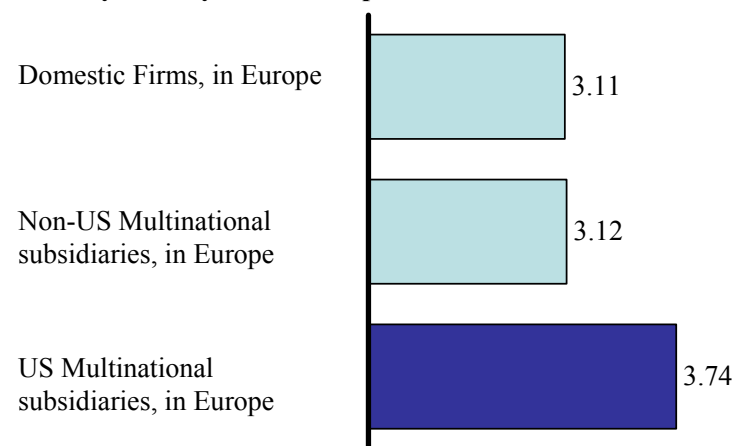
**Figure 2a: Management practices,
firms by country of location**



**Figure 1b: Organizational devolvment,
firms by country of ownership**



**Figure 2b: Management practices,
firms by country of ownership**



Notes: In Figures 1a and 1b the “Organizational devolvment” score is the average score for the 2 organizational questions for 548 firms in the US (219), UK (98) and France and Germany (231). The questions are taken exactly from Bresnahan et al. (2002) covering “Task allocation” and “Pace setting” where a higher scores indicate greater worker autonomy. Full survey details in Bloom and Van Reenen (2005). In Figures 2a and 2b the “Management Practice” score is the average score for 18 questions on management practices where 1 is “*worst practice*” and 5 is “*best practice*” for 733 firms from the US (290), UK (151) and France and Germany (292). Full survey details in Bloom and Van Reenen (2005). In Figure 1a the differences between “European” and “US” firms is significant at the 1% level with a standard error of 0.143. In Figure 1b the difference between the “US Multinational subsidiaries” and the “Domestic Firms” is significant at the 10% level with a standard error of 0.084. In Figure 2a the difference between the “European” and “US” firms is significant at the 1% level with a standard-error of 0.057. In Figure 2b the difference between the “US Multinational subsidiaries” and the “Domestic Firms” is significant at the 1% level with a standard error of 0.169.

II. MODELS OF IT AND PRODUCTIVITY

Following Klette (1999) establishments in an industry are assumed to be constrained by a production function $Q_{it} = A_{it}F_t(X_{it})$ where Q is gross output of establishment i at time t , A_{it} is an establishment specific productivity factor and $F_t(.)$ is a part of the production function common to all plants. The production function relationship can be expressed in terms of logarithmic deviations from a point of reference⁵. This reference point can be thought of as the representative plant's level of output and inputs for each year. Rewriting the production function in terms of logarithmic deviations from this reference point (denote such a transformed variable $\tilde{x}_{it} \equiv \ln X_{it} - \ln X_t$ where X_t is the reference point⁶)

$$\tilde{q}_{it} = \tilde{a}_{it} + \alpha_{it}^M \tilde{m}_{it} + \alpha_{it}^L \tilde{l}_{it} + \alpha_{it}^K \tilde{k}_{it} + \alpha_{it}^C \tilde{c}_{it} \quad (1)$$

where C is the IT capital stock of computer hardware, K is non-IT capital, L is labour, M is materials and a lower case letter denotes a natural logarithm ($x = \ln X$, etc). The α_{it}^j is the output elasticity for factor j evaluated at an internal point between X_{it} and X_t .

We are particularly interested in the role of IT capital and whether the impact of computers on productivity is systematically higher for the plants belonging to US firms in the sectors that intensively use IT and that appear to have been responsible for the bulk of the US productivity acceleration since the mid 1990s. Consider parameterizing the output elasticities in equation (1) as:

$$\alpha_{it}^J = \alpha_h^{J,0} + \alpha_h^{J,USA} D_{it}^{USA} + \alpha_h^{J,MNE} D_{it}^{MNE} \quad (2)$$

where D_{it}^{USA} denotes that the establishment is owned by a US firm in year t and D_{it}^{MNE} denotes that the establishment is owned by a non-US multinational enterprise (the base case is that firm is a non-multinational purely domestic firm), the sub-script h denotes sector (e.g. industries that use IT

⁵ This uses a version of the multivariate generalized mean value theorem. The production function is therefore much more general than simply Cobb-Douglas.

⁶ We will generally use the four digit industry mean at time t as the reference point for x_t , but we also used alternatives such as the median plant in the same four digit industry in the same year.

intensively vs. non-IT intensive sectors) and the super-script J indicates a particular factor of production (M, L, K, C). We further assume that total plant specific efficiency can be written as:

$$\tilde{a}_{it} = a_i + \delta_h^0 + \delta_h^{USA} D_{it}^{USA} + \delta_h^{MNE} D_{it}^{MNE} + \gamma_h' \tilde{z}_{it} + u_{h,it} \quad (3)$$

where z are other observable factors influencing productivity such as establishment age, region, whether the establishment is part of a multi-plant group, etc. So the general form of the production function that we will estimate is (combining equations (1) through (3)):

$$\begin{aligned} \tilde{q}_{it} = & \sum_{M,L,K,C \in J} \alpha_h^{J,0} \tilde{x}_{it}^J + \sum_{M,L,K,C \in J} \alpha_h^{J,USA} D_{it}^{USA} \tilde{x}_{it}^J + \sum_{M,L,K,C \in J} \alpha_h^{J,MNE} D_{it}^{MNE} \tilde{x}_{it}^J \\ & + a_i + \delta_h^{USA} D_{it}^{USA} + \delta_h^{MNE} D_{it}^{MNE} + \delta_h^0 D_{it}^0 + \gamma_h' \tilde{z}_{it} + u_{h,it} \end{aligned} \quad (4)$$

where $x^M = m$, etc.

Note that although we will estimate equation (4) in some specifications, most of the interactions between factor inputs and ownership status are insignificantly different from zero. One interaction that will stand out is that between the US ownership dummy and IT capital: the coefficient on computer capital is significantly higher for US firms than for other multinationals and/or domestic firms. Consequently our preferred specifications are usually of the form:

$$\begin{aligned} \tilde{q}_{it} = & \alpha_h^M \tilde{m}_{it} + \alpha_h^L \tilde{l}_{it} + \alpha_h^K \tilde{k}_{it} + \alpha_h^{C,0} \tilde{c}_{it} + \alpha_h^{C,USA} D_{it}^{USA} \tilde{c}_{it} + \alpha_h^{C,MNE} D_{it}^{MNE} \tilde{c}_{it} \\ & + a_i + \delta_h^{USA} D_{it}^{USA} + \delta_h^{MNE} D_{it}^{MNE} + \delta_h^0 D_{it}^0 + \gamma_h' \tilde{z}_{it} + u_{h,it} \end{aligned} \quad (5)$$

where the key hypotheses are whether $\alpha_h^{C,USA} D_{it}^{USA} = 0$ and/or $\alpha_h^{C,USA} D_{it}^{USA} = \alpha_h^{C,MNE} D_{it}^{MNE}$.

Under the assumptions of perfectly competitive factor input markets and product markets, in the long-run the parameters on each factor input will be equal to their share of revenue. Under these

assumptions, standard growth accounting exercises can be performed. Denote the factor share of J as s_{it}^J

$$s_{it}^J = \left(\frac{W_{it}^J X_{it}^J}{P_{it} Q_{it}} \right) \quad (6)$$

where W^J is the factor price of input X^J .

Of course, these are very strong assumptions so it is of interest to estimate equations (4) and (5) directly and see whether “normal returns” hold in practice to all factors. In particular, we are interested in whether there may be larger than expected coefficients on IT capital, particularly for US owned establishments.

An alternative to estimating equation (4) is to consider a TFP based specification. We consider “measured TFP” in differences, $\Delta_d MTFP$

$$\Delta_d MTFP = \Delta_d \tilde{q}_{it} - \bar{s}_{it}^M \Delta_d \tilde{m}_{it} - \bar{s}_{it}^L \Delta_d \tilde{l}_{it} - \bar{s}_{it}^K \Delta_d \tilde{k}_{it} - \bar{s}_{it}^C \Delta_d \tilde{c}_{it} \quad (7)$$

where d is the order of differencing (e.g. $d = 1$ implies first differences, $d = 2$ second differences, $x_t - x_{t-2}$ and so on). A bar denotes that the shares are averaged (e.g. the unweighted average of this year’s share and last year’s share for $d = 1$)⁷.

We consider estimating in first or longer differences specifications similar to Brynjolfsson and Hitt (2003). In the context of equation (5) this becomes:

$$\begin{aligned} \Delta_d MTFP_{it} = & b_h^0 \Delta_d \tilde{c}_{it} + b_h^{USA} \Delta_d (D_{it}^{USA} \tilde{c}_{it}) + b_h^{MNE} \Delta_d (D_{it}^{MNE} \tilde{c}_{it}) + \\ & \delta_h^{USA} \Delta_d D_{it}^{USA} + \delta_h^{MNE} \Delta_d D_{it}^{MNE} + \delta_h^0 \Delta_d D_{it}^0 + \gamma_h' \Delta_d \tilde{z}_{it} + \Delta_d u_{h,it} \end{aligned} \quad (8)$$

⁷ We build the factor shares using the industry specific medians by ownership type. See Griffith, Redding and Van Reenen (2004) for a discussion over various ways of measuring TFP.

Under the null of normal returns then all the coefficients on IT capital should be zero ($b_h^0 = b_h^{USA} = b_h^{MNE}$) since $b_h = (\alpha_{it}^C - s_{it}^C)$, etc.

In all specifications we allow for a general structure of the error term that allows for arbitrary heteroscedacity and autocorrelation over time. But there could still be establishment specific unobserved heterogeneity. So we also consider including a full set of establishment level fixed effects (the “within groups” estimator). The fixed effects estimators are more rigorous as there may be many unobservable omitted variables correlated with IT that generate an upwards bias to the coefficient on computer capital. On the other hand, attenuation bias (caused by measurement error in IT and other right hand side variables) will be exacerbated by including fixed effects generating a bias towards zero⁸.

We also want to allow for endogeneity of the factor inputs and take several approaches to dealing with this issue. Our preferred measure is to use the “System GMM” estimator of Blundell and Bond (1998) but we also compare this to a version of the Olley Pakes (1996) estimator. These methods are detailed in Appendix A.

III. DATA

Our dataset is a panel of establishments covering almost all sectors of the UK private sector called the ABI, which is similar in structure to the US Longitudinal Research Database (LRD). The UK poses a useful testing ground because: (a) it has not experienced a US-style productivity acceleration since 1995 (as Basu et al (2003) show) and (b) it is a large recipient of foreign direct investment so we are able to compare across many types of ownership. In addition, unlike the LRD the ABI contains detailed IT data and also covers the non-manufacturing sector from the mid 1990s onwards, which is important because the majority of the sectors that intensively use IT are outside manufacturing. A full description of the datasets used is in Appendix A.

⁸ See Griliches and Mairesse (1998) for a general discussion of this problem with production functions and Brynjolfsson and Hitt, 1995, 1996, 2003) for a discussion specifically on IT.

We build up IT capital stocks from the IT expenditures using the perpetual inventory method following Jorgenson (2001) keeping to US assumptions over depreciation rates and hedonic prices. We report several ways of dealing with the problem of initial conditions⁹. Our dataset runs from 1995 through 2003, but there are many more observations in each year post 1999. After cleaning we are left with 22,736 non-zero observations. There are many small and medium sized establishments in our sample - the median establishment employs 238 workers and the mean establishment employs 796. At rental prices average IT capital is about 1% of gross output at the unweighted mean (1.5% if weighted by size) or 2.3% of value added. These are similar to the economy wide means in Basu et al, 2003.

We also have a large numbers of multinational establishments in the sample: about 8% of establishments are US owned, 29% are non-US owned and 63% are purely domestic. Multinationals share of employment is even higher and their share of output higher still. US and non-US establishments have about 48% and 46% more employees and about 64% and 51% more value-added than the industry average respectively.¹⁰. This US productivity advantage is partially linked to greater use of inputs: US plants use about 10% more materials/intermediate inputs, 10% more non IT capital and 27% more IT capital than non-US multinationals. Hence, US multinationals are notably more IT intensive than other multinational subsidiaries. Table A3 contains a detailed description of these differences by ownership type

To validate the data we started by running a wide range of investigative OLS, GMM system and Olley-Pakes production function estimations, displayed in full in Appendix A4. In summary, the different estimators produced estimates of the elasticity of output with respect to IT in the range of 0.02 to 0.04. It is reassuring that productivity does indeed have a positive and significant association with IT capital, consistent with the findings from the new micro studies in the US and elsewhere.

⁹ Essentially we exploit the fact that we have a long time series of industry level estimates of IT flows and stocks from other studies that use the input-output matrices (e.g. O'Mahony and Van Ark, 2003 ; Basu et al, 2003). We impute an estimate of an establishment's initial IT stock based on its observed flow of IT expenditure and the industry information. Because we have a short time series for many firms we are careful to check the robustness of the results for different assumptions over the treatment of the initial year of the IT stock. We consider different ways to impute the initial value, and also show below that using just the flow measures (i.e. not using any imputations for the initial year) gives us qualitatively similar results.

¹⁰ This is consistent with evidence that the plants of multinational US firms are more productive both on US soil (Doms and Jensen, 1998) and on foreign soil (Criscuolo and Martin (2005), Griffith, Simpson and Redding (2002)).

Although the coefficient is larger than the share of IT capital in output (which is about 1% to 1.5%) the difference is not as dramatic as has been found in other studies such as Brynjolfsson and Hitt (2003)¹¹. We will discuss possible reasons for this below, but an obvious reason is that IT impacts may be heterogeneous between US firms and non-US firms.

We also considered several experiments changing our assumptions concerning the construction of the IT capital stock. First, there is uncertainty over the exact depreciation rate for IT capital, so we experimented with a number of alternatives including the extreme case of 100% depreciation and just working with the flows. Second, we do not know the initial IT capital stock for ongoing firms the first time they enter the sample. Our base method is to assume that the IT investment rate is the same as the industry average IT investment rate in the base period. An alternative is to assume that the plant's share of the IT stock is the same as its share of employment in the industry in the base period. Appendix Table A5 shows as expected that in both cases this affected the magnitude of the coefficient on IT, but it always remained positive and significant.

IV. RESULTS

IV.A. US Multinationals, IT and productivity

Table 1 contains the key results for the paper which is the productivity advantage of US multinationals is linked to the use of IT. Column (1) estimates the basic production function including a dummy variables for whether or not the plant was owned by a US multinational ("USA") or a non-US multinational ("MNE") with plants who are domestically owned being the omitted base. US establishments are 8.5% more productive than UK domestic establishments and non-US multinationals are 4.8% more productive. The difference between the US and non US MNE coefficients is also significant at the 5% level (p-value = 0.001).

¹¹ There are a number of possible reasons for the differences. Most obviously, Brynjolfsson's data is from the US whereas ours is from the UK- we show that there appears to be larger IT coefficients for US firms than for UK firms. Other differences include (a) we are using more disaggregated data (establishments rather than worldwide accounts of firms); (b) our measure of IT capital is constructed in the standard way from flows of expenditure whereas BH use a measure based on pricing different pieces of IT equipment; (c) our sample is much larger and covers a more recent time period (d) our estimation techniques are different. We investigate some of these below.

The second column of Table 1 includes the IT hardware measure which enters significantly and reduces the coefficients on the ownership dummies. US plants are more IT intensive than other plants and this explains some of the productivity gap. But it only accounts for about 12% of the initial gap, i.e. about one percentage point of initial 8.5% productivity gap. Column (3) includes two interaction terms: one between IT capital and the US dummy and the other between IT capital and the non-US multinational dummy. These turn out to be very revealing. The interaction between the US dummy and IT capital is positive and significant at conventional levels. According to column (3) doubling the hardware stock is associated with an increase in productivity of 5.2% for a US MNE but only 4.1% for a domestic firm. Non-US multinationals are insignificantly different from domestic UK firms in this respect: we cannot reject that the coefficients on IT are equal for domestic UK firms and non-US multinationals. It is the US firms that are distinctly different. In fact, the linear US dummy is now insignificantly different from zero. Interpreted literally, this means that we can “account” for all of the US MNE advantage by their superior use of IT. Hypothetically, US plants that have less than about £1,000 of IT capital (i.e. $\ln(C) = 0$) are no more productive than their UK counterparts (no US plants in the sample have IT spending this low, of course).

To investigate the industries that appear to account for the majority of the productivity acceleration in the US we split the sample into “highly IT using intensive sectors” in column (4) and “low IT using intensive sectors” in column (5). Sectors that use IT intensively includes retail, wholesale and printing/publishing.¹² The US interaction with IT capital is much stronger in the IT intensive sectors, being insignificantly different from zero in the less IT intensive sectors (even though there are twice as many firms in these industries). The final three columns include a full set of establishment fixed effects. The earlier pattern of results is repeated with a higher value of the interaction than in the non-fixed effects results. In particular, column (7) demonstrates that US plants have significantly higher productivity of their IT capital stocks than domestic firms or other multinationals. A doubling of the IT capital stock is associated with 2% higher productivity for a domestic plant, 2.5% for a non-US multinational but 5% higher productivity for a plant owned by a US multinational.

IV.B. Robustness Tests of the US Multinational effect on IT

Table 2 presents a series of tests showing the robustness of the main results - we focus on the fixed effects specification in the IT intensive sectors which are the most demanding specifications. The first column represents our baseline results from column (7) in Table 1. Column (2) simply reiterates what we have already observed in Table 1 by estimating the production function with a full set of interactions between the US dummy and *all* the factor inputs. None of the additional non-IT factor input interactions are individually significant and the joint test at the base of the column of the additional interactions shows that they are insignificant (for example the joint test of the all the US interactions except the IT interaction has a p-value of 0.76). We cannot reject the specification in column (1) as a good representation of the data against the more general interactive models of Table 1.¹³

A concern is that we may be underestimating the true IT stock of US multinationals in the initial year generating our interaction term due to greater measurement error of IT capital for the US establishments. To check this issue we turn to an alternative IT survey (the E-commerce Survey, described in the Appendix) that has data on the proportion of workers in the establishment who are using computers. This is a pure “stock” measure so is unaffected by the initial conditions concern¹⁴. In Column (3) we replace out IT capital stock measure with this proxy. Reassuringly we still find a positive and significant US ownership interaction. The fourth column of Table 2 implements an alternative way of examining whether IT returns are higher for US multinationals by aggregating IT and non-IT capital into total capital and including an additional variables for the proportion of IT capital in the total capital stock and its interactions with the ownership dummies. All terms are positive and the US interaction with IT is significantly different from zero at the 1% level. Another concern is that the US*IT interaction reflects some other non-linearity in the production function.

¹² See Appendix Table A1 for a full list

¹³ Table A6 tests allowing *all* coefficients to differ by ownership type. In columns (1) to (3) – covering the IT intensive sectors – we reject equality of coefficients across ownership types at the 1% level, while in columns (4) to (6) – covering the non-IT intensive sectors – we can not reject equality. Thus, this is consistent with our results that the coefficient on all non-IT inputs are the same across ownership types, and the returns to IT are higher for US owned establishments in the IT intensive sectors.

¹⁴ Our IT stock measure is more appropriate theoretically as it is built in an entirely analogous way to the non-IT stock and comparable to best practice existing work. The E-Commerce Survey is available for three years (2001-2003), but the majority of the sample is observed only for one period, so we do not control for fixed effects.

We tried including a much fuller set of interactions and higher order terms, but these were insignificant. Column (5) shows the results of including all the pairwise interactions of materials, labour, IT capital and non-IT capital and the square of each of these factors. The additional terms are jointly insignificant (p -value = 0.32) and the US interaction with IT remains basically unchanged. Column (6) presents a value added based specification instead of an output based specification. The results are similar to using gross output (although the coefficients are larger of course).

Another possible explanation for the higher productivity of IT in US firms is that US multinationals may be disproportionately represented in specific industries in which the returns to IT are particularly high. The interaction of IT capital with the US dummy would then capture omitted industry characteristics rather than a “true” effect linked to US ownership. To test for this potential bias we included in our regression as an additional control the percentage of US multinationals in the specific four digit SIC industry (“USA_IND”)¹⁵. We also construct a similar industry level variable for the non-US multinationals (“MNE_IND”). There is no evidence that IT returns are apparently higher in sector with a larger US MNE presence (see column (7)).

Next, we considered the role of skills. Our main control for labour quality in Table 1 is the inclusion of establishment specific fixed effects which, so long as the labour quality does not change too much over time, should control for the omitted human capital variable. As an alternative we matched in education information at the industry-region level from an individual level survey, the Labor Force Survey¹⁶. In the specifications without fixed effects, there was some evidence for a positive and significant interaction between skills and IT consistent with complementarity between technology and human capital. The US*IT capital interaction remained significant¹⁷. Including fixed effects, however, renders the skills variables and their interactions insignificant (even though US*IT interaction remains significant). Interactions between the US dummy and skills were insignificant in all specifications. Another alternative is to assume that wages reflect marginal

¹⁵ The variable is constructed as an average between 1995 and 2003 and is built using the whole ARD population.

¹⁶ The skills measure is the proportion of workers in a two digit industry who had a college degree from the LFS (Labor Force Survey) separately for each year and region (see Data Appendix)

¹⁷ The linear educational term is negative in column (7) but it is positive at the mean (e.g. dropping the skills*IT interaction the marginal effect of education is 0.134).

products of workers so that conditioning on the average wage in the firm is sufficient to control for human capital¹⁸. Interactions between the US dummy and average wages in the plant were also insignificant (p-value = 0.512).

We also implemented a large number of other robustness tests, many of which are reported in Appendix A. These included many alternative econometric estimation techniques, different versions of dealing with measurement error in the capital stocks and more flexible specifications of the production function. One issue is that US firms may be more productive in the UK because the US is geographically further away than the other multinationals (mainly European countries) and only the most productive firms are able to overcome the fixed costs of distance. To test this we divided the non-US multinational dummy into European vs. non-European firms. Under the distance argument, the non-European firms would have to be more productive to be able to set up plant in the UK. In the event, the European and non-European multinationals were statistically indistinguishable from each other – it was again the US multinationals that appeared different¹⁹.

IV.C. US Multinational Takeovers of UK establishments

One possible explanation for our results is that US firms “cherry pick” the best establishments with the highest potential returns from IT. This would generate the positive interaction we find but it would be entirely due to selection on unobserved heterogeneity rather than higher returns to IT due to US ownership. To look at this issue we examined the sub-sample of establishments who were, at some point in our sample period taken over by another firm, considering both US and non-US acquirers. In columns (1) and (2) of Table 3 we start by estimating our standard production functions with and without IT respectively for all establishments that are eventually taken over in their *pre-takeover* years. The coefficients on the observable factors are very similar to those for the whole sample in columns (1) and (2) of Table 1. The US and non-US ownership dummies are also

¹⁸ The problem is that wages may control for too much as some proportion of wages is almost certainly related to other factors apart from human capital. For example, in many models, firms with high productivity will reward even homogenous workers with higher wages (see Van Reenen (1996) on rent sharing).

¹⁹ In specifications of column (2) Table 1 the EU dummy was 0.042 compared to 0.040 for the non-EU, non-US multinational dummy (the US dummy was 0.075). All were significantly more productive than domestic establishments. The interactions of these extra dummies with IT capital were always insignificant (e.g. In the specification of Table 1 column (3) the coefficient on the non-US non-EU multinational dummy was 0.006 with a standard error of 0.006 whereas the US interaction was 0.011 with a standard error of 0.005).

not significant, suggesting the establishments they take over are not *ex ante* more productive than those acquired by domestic UK firms.

In column (3) of Table 3 we interact the IT capital stock with a US and a non-US multinational ownership dummy, again estimated on the *pre-takeover* data. We see that neither interaction is significant – that is *before* establishments are taken over by US firms they do not show a significantly higher return to their IT. So, US firms also do not appear to be selecting establishments which provide a higher return to IT. In columns (4) and (5) we run a similar production function check on the *post-takeover* sample and again observe very similar coefficients to columns (1) and (2) in Table 1, suggesting that these *post* takeover establishments are also similar to the rest of the sample. This time, however, the non-US and US multinational ownership coefficients are positive and significant. Thus, a transfer of ownership from domestic to multinational production is associated with an increase in productivity, particularly for a move to US ownership.

Column (6) is a key result for Table 3. It estimates a specification allowing the IT capital stock coefficient to vary by ownership for the *post* takeover sample. In this group we do indeed see a higher return from IT for US firms, which is significant at the 10% level, but not for non-US owned establishments. Hence, after a takeover by a US MNE establishments significantly increase their returns from IT, but not after a takeover by a non-US MNE. The inclusion of this US interaction also drives the coefficient on the linear US multinational term into insignificance, suggesting the main reason for the improved performance of establishments after a US takeover is linked to the increased return from IT.

The final column of Table 3 breaks down the post takeover period into the first year after the takeover and the subsequent years (throughout the table we drop the takeover year itself as there is likely to be restructuring in that period). The greater productivity of IT capital in establishments taken over by US multinationals is only revealed two and three years after takeover (the interaction is significant at the 5% level whereas the interaction in after the first year is insignificant). This is consistent with the idea that US firms take a couple of years to get the organizational capital of the firm in place before obtaining higher productivity gains from IT. Domestic and other multinationals again reveal no pattern with all dummies and interactions remaining insignificant.

Table 4 explores this idea further by running IT investment equations for the establishments that have been taken over at some point. The first column focuses on the pre-takeover period and shows that the establishments who were subsequently taken over by US firms were no more IT intensive than other establishments taken over by non-US multinationals or domestic UK firms. The second column contains the results from the post-takeover period. Again, there is evidence that US establishments invest significantly more in IT than other statistically similar establishments taken over by other firms. The final column splits the takeover period into the first year post-takeover and then the second and third. As with productivity, the boost to IT in US takeovers is only revealed two years and more after the takeover has occurred.

As another cut on the cherry-picking concept we ran a probit of US takeovers where the dependent variable is equal to unity for establishments who are taken over by a US firm and otherwise. We find that IT intensity is insignificant in this regression. Hence, US firms do not appear to target establishments that are particularly IT intensive prior to the takeover, but instead increase the IT intensity of these establishments post-takeover.²⁰

IV.D. Further Investigations

TFP Specifications

Although it is clear that the coefficients in the production function on IT capital (between 0.03 and 0.04) exceed the expected factor shares in revenues (0.01 to 0.02), we confirm these results directly by examining TFP growth equations that are popular in the literature. These take the form of equation (7) and these results are in Table 5. In column (1) we present first differenced results that suggest that the coefficient on IT capital is about 0.014 higher than we would expect from the standard growth accounting assumptions (and this is significant at conventional levels). The next three columns look at the same regressions but using longer differences. The second column contains “second differences” by which we mean all variables are expressed relative to their values two years previously ($x_t - x_{t-2}$). The third column presents third differences and the fourth column

²⁰ After a take-over by a US multinational establishments increase their IT capital per hear by 30%, which is significantly different from takeovers by non-US multinational establishments at the 5% level.

fourth differences. There is a tendency for the coefficients to increase as we increase the length of differencing, but the IT variable remains significant. Relative to other estimates (e.g. Bynjolfsson and Hitt, 2003) the increase in the magnitude of the coefficient is not dramatic (from 0.0137 to 0.0155). Typically some of the increase in coefficients when moving from short to long differences is ascribed to attenuation bias. It may be that measuring IT carefully at the establishment (rather than firm or industry level) helps to alleviate some of these problems of measurement error.

The final three columns of Table 5 include interactions between IT and ownership types. Interestingly these interactions turn out not to be significant (although the point estimates are higher on the US interactions than the other MNE interactions). This is unsurprising. If the production function contains interactions of organizational capital with IT but there is no (log) linear organizational capital term, then the IT factor share should reflect the higher average level of organizational capital in US firms. Measured TFP differences should be the same.

Software

Could the higher returns to IT be simply due to greater software intensity in US firms? We have some information of software expenditure that we can use to build analogous measures of the software IT stock. When included in the specifications these stocks are positive and significant, but the hardware coefficient is only slightly reduced. Using the same specification as Table 1 column (2) when the software stock is included it has a coefficient of 0.0138 and a standard error of 0.0038. Conditional on this software stock the hardware coefficient is 0.0284 with a standard error of 0.0049. The hardware interaction with the US remains positive and significant when software is included. For example in column (7) of Table 1 the hardware interaction has a coefficient of 0.0366 with a standard error of 0.0169. One concern with comparing software data for multinationals versus domestic firms may be that some multinational software development happens in the home country, which is not fully measured through transfer pricing, so that multinational subsidiary software expenditure under-reports total software inputs. This emphasizes the importance, however, of comparing US multinationals to non-US multinationals that should have similar “underreporting” issues to the extent these occur. As noted above, whether or not we include these software

measures, US multinationals still obtain a significantly higher return from IT inputs than either domestic firms or other non-US multinationals.

V. CONCLUSIONS

Using a large and original establishment level panel dataset we find robust evidence that IT has a positive and significant correlation with productivity even after controlling for many factors such as fixed effects. We estimate that a doubling of the IT stock is associated with an increase in productivity of between 2% and 4%. The most novel result is that we can account for the US multinational advantage in conventionally measured TFP by their higher returns to using IT capital. Furthermore, the stronger association of IT with productivity for US firms is confined to the same “IT using intensive” industries that largely accounted for the US “productivity miracle” since the mid 1990s. US firms in the UK were able to get significantly more productivity out of their IT than other multinational (and domestic British) firms, even in the context of a UK environment. This suggests that part of the IT-related productivity gains in the US may be due to the management/organizational capital of firms rather than simply the “natural advantages” (geographical, institutional or otherwise) of the US environment.

A major research tasks remain in understanding *why* US firms are able to achieve these “IT friendly” organizational forms and their European counterparts cannot. It could be due to timing – US firms were closer to the development of the new wave of IT producers and so were the first to learn about them. In this scenario European firms will quickly catch up (although there is little evidence of this happening so far). A second explanation is that US firms are “leaner and meaner” than their European counterparts due to tougher competitive conditions in their domestic markets and are therefore intrinsically quicker to adapt to revolutionary new technologies. Alternatively, US firms may be more organizationally devolved for historical reasons due to their greater supply of college levels skills, relative absence of family owned firms and/or their history of technological leadership (see Acemoglu et al, 2005), rendering them better equipped to adopt new IT

technologies. Under these scenarios Europe will resume the catching up process with a much longer lag than is conventionally thought.

REFERENCES

- Acemoglu, D., Aghion, P., Lelarge, C., Van Reenen, J. and Zilibotti, F. (2005) "Technology, Information and the Decentralization of the firm" LSE mimeo
- Arellano, M. and Bond, S. (1991), "Some tests of specification for panel data: Monte Carlo evidence and an application to employment functions", *Review of Economic Studies*, 58, 277-297
- Basu, Susanto, Fernald, John G., Oulton, Nicholas, Srinivasan, Sylaja (2003) "The Case of the Missing Productivity Growth: Or, Does information technology explain why productivity accelerated in the United States but not the United Kingdom?" *NBER Macro-economics Annual*
- Blanchard, Olivier (2004) "The Economic Future of Europe" *Journal of Economic Perspectives*, 18,4, 3-26
- Bloom, N. and Van Reenen, J. (2006), "Measuring and explaining management practices across firms and countries", Centre for Economic Performance mimeo.
- Blundell, R. and Bond, S. (1998) "Initial Conditions and Moment Restrictions in dynamic panel data models" *Journal of Econometrics*, volume 88, 115-143.
- Blundell, R. and Bond, S. (2000) "GMM Estimation with persistent panel data: an Application to production functions" *Econometric Reviews*, 19(3), 321-340.
- Bresnahan, Tim, Brynjolfsson, Erik and Hitt, Lorin (2002) "Information Technology, Workplace Organization and the Demand for skilled labor" *Quarterly Journal of Economics*, 117(1), 339-376
- Brynjolfsson, Erik and Hitt, Lorin (2000) "Beyond Computation: Information Technology, Organisational Transformation and Business Performance." *Journal of Economic Perspectives*, Vol. 14 No. 4, 23-48
- Brynjolfsson, Erik Hitt, Lorin and Yang, Shinkyu (2002) "Intangible Assets: Computers and Organizational Capital." *MIT Sloan*, Paper 138
- Brynjolfsson, Erik and Hitt, Lorin (2003) "Computing Productivity : Firm Level Evidence" *Review of Economics and Statistics*, 85 4, 793-808
- Caroli, Eve, and Van Reenen, J. (2001) "Skill biased organizational change? Evidence from British and French establishments" *Quarterly Journal of Economics* CXVI, No. 4, 1449-1492
- Chennells, Lucy, and John Van Reenen, " (2002) "The effects of technical change on skills, wages and employment: A Survey of the Micro-econometric evidence" Chapter 5 in L'Horty, Y. and Greenan, N., and Mairesse, J. *Productivity, Inequality and the Digital Economy* MIT Press 175-225
- Colecchia, A. and Schreyer (2002) "ICT Investment and Economic Growth in the 1990s : Is this United States a Unique Case ? " *Review of Economic Dynamics*, 408-442

- Crepon, B. and Heckel, T. (2002) "Computerization in France : an Evaluation based on individual company data" *Review of Income and Wealth*, 1, 1-22
- Criscuolo, Chiara and Martin, Ralf (2004) "Multinationals and US Productivity Leadership: Evidence from Great Britain", Centre for Economic Performance Discussion Paper No. 672
- Doms, M., Dunn, W., Oliner, S., Sichel, D. (2004) "How Fast Do Personal Computers Depreciate? Concepts and New Estimates", NBER Working Paper No. 10521
- Doms, M. and Jensen, J. (1998) "Comparing Wages, skills and productivity between domestically owner manufacturing establishments in the United States" in Robert Baldwin, R.E.L. and Richardson, (eds) *Geography and Ownership as bases for economic accounting*, 235-258, Chicago: University of Chicago
- Feenstra, R. and Knittel, C. (2004) "Re-assessing the US quality adjustment to computer prices: The role of durability and changing software" NBER Working Paper 10857
- Geske, Ramey and Shapiro (2004) "Why do computers depreciate?" NBER Working Paper 10831
- Griffith, R., Simpson, H. and Redding, S. (2002) "Productivity Convergence and Foreign Ownership at the Establishment Level" Centre for Economic Policy Research Discussion Paper No. 2765
- Griliches, Zvi, and Jacques Mairesse (1998) "Production functions: The Search for Identification" in Scott Ström (ed.), *Essays in Honour of Ragnar Frisch*, Econometric Society Monograph Series, (Cambridge: Cambridge University Press, 1998).
- Haltiwanger, J., Jarmin, R. and Schank, T. (2003) "Productivity, Investment in ICT and market experimentation: Micro evidence from Germany and the U.S" Center for Economic Studies Discussion Paper 03-06
- Haskel, J. and Martin, R. (2002) "The Productivity Spread", Ceriba mimeo
- Klette, Tor Jakob (1999) "Market power, scale economies and productivity: Estimates from a panel of establishment data", *Journal of Industrial Economics*, 47, 451-76.
- Klette, Tor and Griliches, Zvi (1996) "The inconsistency of Common Scale estimators when output prices are unobserved and endogenous" *Journal of Applied Econometrics*, 11, 343-361
- Jorgenson, Dale and Stiroh, Kevin (2000) "Raising the Speed Limit: US Economic Growth in the Information Age." *Brookings Papers on Economic Activity*, 1 :125-211
- Jorgenson, D. W. (2001) "Information technology and the U. S. economy", *American Economic Review*, 91(1), 1-32.
- Oliner, Stephen and Sichel, Daniel (2000). "The resurgence of growth in the late 1990s: is information technology the story?" *Journal of Economic Perspectives*, 14(4), 3-22

Oliner, Stephen and Sichel, Daniel (2005). "The resurgence of growth in the late 1990s: Update" , mimeo Federal Reserve Bank, Washington

Olley, G. Steven, Pakes, Ariel (1996) "The Dynamics of Productivity in the Telecommunications Industry." *Econometrica* Vol. 64, No. 6, 1263-1297

O'Mahony, Mary and van Ark, Bart, eds. (2003), *EU Productivity and Competitiveness: An Industry Perspective Can Europe Resume the Catching-up Process?*, Office for Official Publications of the European Communities, Luxembourg, 2003.

Stiroh, Kevin (2002a), "Information Technology and the U.S. Productivity Revival: What Do the Industry Data Say?", *American Economic Review*, 92(5), December, 1559-1576.

Stiroh, Kevin, (2002b) "Reassessing the Role of IT in the Production Function: A Meta analysis", *mimeo, Federal Reserve Bank of New York*

Van Ark, Bart, Inklaar, Robert, and McGuckin Robert H. (2002) "'Changing Gear.' Productivity, ICT and Service Industries: Europe and the United States." *Research Memorandum GD-60 University of Groningen , Groningen Growth and Development Centre*

Van Reenen, J (1996) "The Creation and Capture of Economic Rents: Wages and Innovation in a Panel of UK Companies" *Quarterly Journal of Economics* (February 1996) CXI, 443, 195-226

TABLE 1 – ALLOWING THE I.T. COEFFICIENT TO DIFFER BY OWNERSHIP STATUS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Dependent variable : Ln(GO), ln(Gross Output)							
Sectors	All Sectors	All Sectors	All Sectors	IT Using Intensive Sectors	Non IT Using Intensive Sectors	All Sectors	IT Using Intensive Sectors	Non IT Using Intensive Sectors
Fixed effects	NO	NO	NO	NO	NO	YES	YES	YES
Ln(C) IT capital	-	0.0434*** (0.0023)	0.0414*** (0.0025)	0.0357*** (0.0032)	0.0441*** (0.0034)	0.0293*** (0.0045)	0.0206*** (0.0066)	0.0271*** (0.0053)
USA*ln(C) USA ownership*IT capital	-	-	0.0108** (0.0047)	0.0191** (0.0075)	0.0066 (0.0060)	0.0084 (0.0093)	0.0295* (0.0155)	0.0009 (0.0108)
MNE*ln(C) Non-US multinational *IT capital	-	-	0.0037 (0.0028)	-0.0002 (0.0037)	0.0072* (0.0040)	-0.0016 (0.0050)	0.0046 (0.0081)	-0.0017 (0.0065)
Ln(M) Materials	0.5472*** (0.0081)	0.5383*** (0.0080)	0.5385*** (0.0080)	0.6138*** (0.0138)	0.5010*** (0.0100)	0.4662*** (0.0193)	0.5596*** (0.0275)	0.4115*** (0.0266)
Ln(K) Non-IT Capital	0.1295*** (0.0066)	0.1176*** (0.0063)	0.1178*** (0.0063)	0.1020*** (0.0082)	0.1344*** (0.0085)	0.1638*** (0.0153)	0.1396*** (0.0226)	0.2112*** (0.0224)
Ln(L) Labour	0.3152*** (0.0062)	0.2864*** (0.0062)	0.2858*** (0.0062)	0.2337*** (0.0098)	0.3031*** (0.0076)	0.3170*** (0.0197)	0.2537*** (0.0261)	0.3385*** (0.0247)
USA USA Ownership	0.0847*** (0.0109)	0.0745*** (0.0106)	0.0155 (0.0257)	-0.0566 (0.0394)	0.0510 (0.0339)	-0.0175 (0.0557)	-0.1671* (0.0925)	0.0157 (0.0646)
MNE Non-US multinational	0.0478*** (0.0067)	0.0414*** (0.0066)	0.0234 (0.0148)	0.0307 (0.0197)	0.0079 (0.0202)	0.0436 (0.0298)	-0.0090 (0.0516)	0.0451 (0.0363)
Observations	22,736	22,736	22,736	7,905	14,831	22,736	7,905	14,831
Adjusted R Squared	0.95	0.96	0.96	0.97	0.95	0.99	0.99	0.99

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variable in all columns is the log of gross output. The time period is 1995-2003. All variables are expressed in deviations from the 4 digit SIC mean in the same year. The estimation method in all columns is OLS. All columns include age, foreign ownership and region dummies and a dummy taking value one if the firm belongs to a multi-firm enterprise group as additional controls. Columns (6) to (8) include establishment level fixed effects. Standard errors in brackets under coefficients in all columns are clustered by firm (i.e. robust to heteroskedacity and autocorrelation of unknown form). See Appendix B for definition of IT using intensive sectors.

TABLE 2 – ROBUSTNESS TESTS ON PRODUCTION FUNCTIONS

Experiment	(1) Baseline Specification	(2) All Inputs Interacted	(3) Alternative IT Measure	(4) Alternative functional form for IT	(5) Full “Translog” interactions	(6) Value Added	(7) US FDI in the 4 digit industry	(8) Skills
Dependent variable	ln(GO)	ln(GO)	Ln(GO/N)	ln(GO)	ln(GO)	ln(VA)	ln(GO)	ln(GO)
Ln(C)	0.0206***	0.0188***	0.0794***	-	0.0180***	0.0498***	0.0165**	0.0242***
IT capital	(0.0066)	(0.0067)	(0.0182)		(0.0061)	(0.0140)	(0.0068)	(0.0070)
USA*ln(C)	0.0295*	0.0434**	0.1289***	-	0.0286*	0.0670*	0.0259*	0.0165**
USA ownership*IT capital	(0.0155)	(0.022)	(0.0396)		(0.0150)	(0.0363)	(0.0156)	(0.0082)
MNE*ln(C)	0.0046	0.005	0.0117	-	-0.0000	-0.0087	0.0029	0.0037
Non-US multinational *IT capital	(0.0081)	(0.0097)	(0.0259)		(0.0075)	(0.0195)	(0.0084)	(0.0075)
SKILLS*ln(C)	-	-	-	-	-	-	-	0.0485**
College %*IT capital								(0.0204)
Ln(M)	0.5596***	0.5582***	0.5565***	0.5598***	0.2532	-	0.5603***	0.6269***
Materials	(0.0275)	(0.0293)	(0.0152)	(0.027)	(0.1922)		(0.0273)	(0.0126)
Ln(K)	0.1396***	0.1459***	0.1112***	-	0.2523***	0.3119***	0.1390***	0.1042***
Non-IT Capital	(0.0226)	(0.0225)	(0.0114)		(0.0904)	(0.0433)	(0.0224)	(0.0083)
Ln(Total_K)	-	-	-	0.1687***	-	-	-	
Non IT capital + IT capital				(0.0216)				
Ln(L)	0.2537***	0.2531***	-0.0040	0.2511***	0.4044**	0.5818***	0.2558***	0.2154***
Labour	(0.0261)	(0.0284)	(0.0038)	(0.0245)	(0.1882)	(0.0462)	(0.0264)	(0.0098)
USA	-0.1671*	0.1096	-0.0234	-0.0324	-0.1595*	-0.3656*	-0.1479	-0.0653
USA Ownership	(0.0925)	(0.3409)	(0.0253)	(0.0376)	(0.0870)	(0.2109)	(0.0931)	(0.0431)
MNE	-0.009	0.0346	0.0244	0.0105	0.0096	0.0892	-0.0002	-0.0051
Non-US multinational	(0.0516)	(0.2003)	(0.0158)	(0.0214)	(0.0464)	(0.1186)	(0.0526)	(0.0641)
USA*ln(M)	-	0.0034	-	-	-	-	-	-
USA ownership*materials		(0.0475)						
MNE*ln(M)	-	0.0051	-	-	-	-	-	-
Non-US multinational *materials		(0.0278)						

USA *ln(K)	-	-0.0311	-	-	-	-	-	-
USA ownership*Non IT capital		(0.0574)						
MNE*ln(K)	-	-0.0144	-	-	-	-	-	-
Non-US multinational *Non IT capital		(0.0201)						
USA *ln(L)	-	-0.0126	-	-	-	-	-	-
USA ownership*Employment		(0.0621)						
MNE*ln(L)	-	0.0075	-	-	-	-	-	-
Non-US multinational *Employment		(0.0316)						
C/(Total Capital)	-	-	-	0.328	-	-	-	-
Fraction of IT Capital in Total Capital				(0.2010)				
USA *[C/(Total Capital)]	-	-	-	0.9139***	-	-	-	-
USA ownership*Fraction of IT Capital in Total K				(0.2928)				
MNE*[C/(Total Capital)]	-	-	-	0.2479	-	-	-	-
Non-US multinational *Fraction of IT Capital in Total Capital				(0.2978)				
Skills	-	-	-	-	-	-	-	-0.2376*
Proportion of people with a college degree in industry-region cell								(0.1351)
USA_IND*ln(C)	-	-	-	-	-	-	0.6863	-
[% of US Multinationals in industry]*IT capital							(0.4960)	
Observations	7905	7905	8509	7905	7905	7905	7905	7751
Adjusted R Squared	0.99	0.99	0.92	0.99	1	0.95	0.99	0.97
Test on joint significance of all the interaction terms, excluding IT interactions (p-value)	-	0.93	-	-	-	-	-	-
Test on joint significance of all the US interaction terms, excluding IT (pvalue)	-	0.76	-	-	-	-	-	-
Test on all the other MNE's interaction terms, excluding IT (p-value)	-	0.9	-	-	-	-	-	-
Test on the other omitted “translog” terms (p-value)	-	-	-	-	0.32	-	-	-

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variable in all columns is the log of gross output. The time period is 1995-2003. All variables are expressed in deviations from the 4 digit SIC mean in the same year. The estimation method in all columns is OLS. All columns except (3) and (8) include plant level fixed effects. Standard errors in brackets under coefficients in all columns are clustered by firm (i.e. robust to heteroskedacity and autocorrelation of unknown form). All columns except (3) are for the sectors that use IT intensively only. All variables in column (3) are expressed in per capita terms. The IT measure in columns (3) is the percentage of people using computers.

TABLE 3. PRODUCTION FUNCTIONS BEFORE AND AFTER TAKEOVERS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sample	before takeover	Before takeover	Before takeover	after takeover	after takeover	After takeover	After takeover
Estimation Method	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Dependent Variable	ln(GO)	ln(GO)	ln(GO)	ln(GO)	ln(GO)	ln(GO)	Ln(GO)
USA USA Takeover	0.0444 (0.0361)	0.0472 (0.0355)	0.1697 (0.1040)	0.0971*** (0.0316)	0.0869*** (0.0300)	-0.0352 (0.0781)	-
MNE Non-US multinational Takeover	-0.0096 (0.0250)	-0.0117 (0.0244)	0.0009 (0.0629)	0.0524** (0.0218)	0.0479** (0.0212)	-0.0166 (0.0446)	-
USA*ln(C) USA Takeover*IT capital	-	-	-0.0224 (0.0179)	-	-	0.0230* (0.0131)	
USA*ln(C) one year after takeover							-0.0051 (0.0143)
USA*ln(C) two and three years after takeover							0.0378** (0.0168)
MNE*ln(C) Non-US multinational Takeover*IT capital	-	-	-0.0025 (0.0113)	-	-	0.0133 (0.0086)	-
MNE*ln(C) one year After takeover							0.0088 (0.0109)
MNE*ln(C) two and three years after takeover							0.0137 (0.0095)
Ln(C) IT capital	-	0.0553*** (0.0075)	0.0560*** (0.0077)	-	0.0444*** (0.0068)	0.0398*** (0.0072)	0.0404*** (0.0071)
Ln(M) Materials	0.5096*** (0.0301)	0.4977*** (0.0297)	0.4972*** (0.0298)	0.5494*** (0.0205)	0.5380*** (0.0204)	0.5380*** (0.0204)	0.5350*** (0.0204)

Ln(K) Non-IT Capital	0.1624*** (0.0247)	0.1454*** (0.0234)	0.1455*** (0.0234)	0.1193*** (0.0162)	0.1096*** (0.0156)	0.1165*** (0.0156)	0.1141*** (0.0156)
Ln(L) Labor	0.3140*** (0.0185)	0.2794*** (0.0183)	0.2799*** (0.0184)	0.3143*** (0.0164)	0.2869*** (0.0166)	0.2852*** (0.0165)	0.2851*** (0.0164)
USA one year after takeover							0.1066 (0.0857)
USA two and three years after takeover							-0.1131 (0.1003)
MNE one year after takeover							-0.0438 (0.0581)
MNE two and three Years after takeover							0.0044 (0.0503)
Observations	2365	2365	2365	3353	3353	3353	3353
Adjusted R-squared	0.97	0.97	0.97	0.97	0.97	0.97	0.97

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The sample is of all establishments who were taken over at some point over the sample period (the omitted base is “domestic takeovers” - UK firms taking over other UK firms). The dependent variable in all columns is the log of gross output. The time period is 1995-2003. All variables are expressed in deviations from the 3 digit SIC mean in the same year. The estimation method is OLS. Columns include age, foreign ownership and region dummies and a dummy taking value one if the firm belongs to a multi-firm enterprise group as additional controls. Standard errors in brackets under coefficients in all columns are clustered by firm (i.e. robust to heteroskedasticity and autocorrelation of unknown form). A takeover is defined as a change in the foreign ownership marker or - for UK domestic firms - as a change in the enterprise group marker. The "before" period is defined as the interval between one and three years before the takeover takes place. The "after" period is defined as the interval between one and three years after the takeover takes place. The year in which the takeover takes place is excluded from the sample.

**TABLE 4: INVESTMENT IN INFORMATION TECHNOLOGY BEFORE AND AFTER
TAKEOVERS BY MULTINATIONAL STATUS**

	(1)	(2)	(3)
Sample	All firms before takeover	All firms after takeover	All firms after takeover
Estimation Method	OLS	OLS	OLS
Dependent Variable	ln(Investment in IT_t)	ln(Investment in IT_t)	ln(Investment in IT_t)
USA –Before USA Takeover	0.0396 (0.1393)	-	
USA –After USA Takeover		0.4239*** (0.1367)	
USA one year after takeover			0.5189*** (0.1862)
USA two and three years after takeover			0.3589** (0.1629)
MNE–Before Non-USA Takeover	0.0660 (0.1167)		
MNE–After Non-USA Takeover		0.2221*** (0.0858)	
MNE one year after non-US takeover			0.3357*** (0.1116)
MNE two and three years after non-US takeover			0.1549 (0.0979)
Ln(L) Labor	1.1100*** (0.0311)	1.0109*** (0.0321)	1.0100*** (0.0321)
USA USA Takeover	0.0444 (0.0361)	0.0472 (0.0355)	0.1697 (0.1040)
MNE Non-US multinational Takeover	-0.0096 (0.0250)	-0.0117 (0.0244)	0.0009 (0.0629)
MNE Non-US multinational Takeover	-0.0096 (0.0250)	-0.0117 (0.0244)	0.0009 (0.0629)
Observations	2149	2928	2928
Adjusted R-squared	0.72	0.66	0.66

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. (the omitted base is “domestic takeovers” - UK firms taking over other UK firms). The dependent variable in all columns is the log of investment in IT. The time period is 1995-2003. All variables are expressed in deviations from the 3 digit industry mean in the same year. The estimation method is OLS. Regressions include age, region dummies and a dummy taking value one if the firm belongs to a multi-firm enterprise group as additional controls. Standard errors in brackets under coefficients in all columns are clustered by firm (i.e. robust to heteroskedasticity and autocorrelation of unknown form). A takeover is defined as a change in the foreign ownership marker or - for UK domestic firms - as a change in the enterprise group marker. The "before" period is defined as the interval between one and three years before the takeover takes place. The "after" period is defined as the interval between one and three years after the takeover takes place. The year in which the takeover takes place is excluded from the sample.

TABLE 5 – TFP BASED SPECIFICATIONS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable	$\Delta \ln(\text{TFP})$	$\Delta \ln(\text{TFP})$	$\Delta \ln(\text{TFP})$	$\Delta \ln(\text{TFP})$	$\Delta \ln(\text{TFP})$	$\Delta \ln(\text{TFP})$	$\Delta \ln(\text{TFP})$
Length of differencing (e.g. first differencing vs. longer differencing)	first	second	third	fourth	first	first	First
Sectors	All	All	All	All	All	IT intensive	Non-IT Intensive
$\Delta \ln(\text{C})$ IT capital	0.0137*** (0.0022)	0.0150*** (0.0030)	0.0154*** (0.0057)	0.0155* (0.0082)	0.0137*** (0.0026)	0.0126*** (0.0037)	0.0142*** (0.0035)
$\Delta[\text{USA} * \ln(\text{C})]$ USA ownership*IT					0.0016 (0.0065)	0.0149 (0.0119)	-0.0064 (0.0076)
$\Delta[\text{MNE} * \ln(\text{C})]$ Non-US multinational *IT					-0.0014 (0.0036)	-0.0021 (0.0059)	-0.0008 (0.0047)
ΔUSA USA Ownership					-0.0035 (0.0379)	-0.0949 (0.0699)	0.0557 (0.0446)
ΔMNE Non-US multinational					0.0143 (0.0204)	0.0171 (0.0376)	0.0109 (0.0245)
Observations	10,122	4,079	920	404	10,122	3,423	6,699

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variable in all columns is the change in “Four factor” Measured Total Factor Productivity (MTFP) where we have calculated MTFP as the change in log output less the growth of all four factor inputs (materials, labour, non-IT capital and IT capital) weighted by their shares in gross output (the weights are specific to the industry, ownership type and year pair). The dependent variable is in annualized differences (first differences in columns (1) through (3) and longer differences in columns (4) through (6) – e.g. column (4) is in second differences as indicated by “order of the differencing”). The time period is 1995-2003. All variables are expressed in deviations from the four digit industry mean in the same year. The estimation method in all columns is OLS. Standard errors in brackets under coefficients in all columns are clustered by firm (i.e. robust to heteroskedacity and autocorrelation of unknown form).

APPENDIX A: DATA AND ADDITIONAL RESULTS

A1 ESTABLISHMENT DATASET ABI

The Annual Business Inquiry (ABI) is the major source of establishment level data in the UK. It underlies the construction of aggregate output and investment in the national accounts and is conducted by the Office of National Statistics (ONS). The ABI is a stratified random sample: sampling probabilities are higher for large establishments (e.g. 100% for all establishments with more than 250 employees). Each establishment has a unique “reporting unit reference number” (RUREF) which does not change when a plant is taken over by a new firm. Data on the production sector (including manufacturing) is in the ABI which has a long time series element (from 1980 and before in some cases). Data on the non-production sector (services) is available for a much shorter time period (from 1997 onwards). The sample is large: in 1998 there are 28,765 plants in the production sector alone (Haskel and Martin, 2002).

The questionnaire sent out on the ABI is extensive and covers all the variables needed to estimate basic production functions. In particular it includes have gross output, value added, employment, wage bill, investment and total materials (this includes all intermediate inputs – energy, materials, etc.). The response rates to the ABI are high because it is illegal not to return the forms to the Office of National Statistics (ONS).

A2 INFORMATION TECHNOLOGY DATASET

Working closely with statisticians and data collectors at ONS we combined the four major IT surveys and matched this into the ABI establishment data using the common establishment code (the Inter-Departmental Business Register, or IDBR). The three IT hardware surveys were not designed to cover exactly the same establishments as contained in the ABI survey, but because there is over-sampling of the larger establishments in all surveys the overlap is substantial, especially for the larger plants.

The main IT surveys include the Business Survey into Capitalized Items (BSCI), the Quarterly Inquiry into Capital Expenditure (QICE) and the Fixed Asset Register (FAR). The ABI also has additional questions on software included since 2000. These surveys are compiled at the reporting unit level, and contain information on the value (in thousands of pounds) of software and hardware acquisitions and disposals. Once the stocks are built within each different survey, we combine them across surveys and, for hardware and software separately, we build across-surveys stocks.²¹ We have some concerns about the accuracy of the plant reports of software expenditure (we are currently investigating these), so we focus in the main part of the paper on the IT hardware stocks.

In the following paragraphs we first describe the different surveys; we then illustrate the details of the PIM used for the construction of the stocks and the procedure followed to build across-surveys variables.

²¹ We are careful to check for differences in coefficients due to the IT measures coming from different surveys. We could not reject the assumption that there were no significant differences in the IT coefficients arising from the fact that the IT stocks were built from different surveys.

Data Sources

Business Survey into Capitalized Items (BSCI). The BSCI asks for detail of acquisitions and disposals of capital in more than 100 categories, including computer hardware and software. The survey is annual and runs between 1998 and 2003; we dropped the 1998 cross section due to concerns over reliability expressed by the data collectors. There is 100% sampling frame for the largest 750 businesses and a stratified random sample of medium sized businesses (between 100 and 750 workers). The BSCI contributes about 1,500 to 2,000 observations for each year between 1999 and 2002.

Quarterly Inquiry into Capital Expenditure (QICE). The QICE provides information on hardware and software investments from 2000Q1 until 2003Q4. The inquiry selects 32,000 establishments each quarter. Of these 32,000 companies, all establishments with over 300 employees are selected each quarter. Businesses with fewer employees are selected for the inquiry randomly. Each quarter one fifth of the random sample is rotated out of the sample and a new fifth is rotated in. The quarterly data have been annualized in several alternative ways and we checked the robustness of the results across these. First, we extrapolated within year for establishments with missing quarters²². As a second alternative, we constructed an indicator that gives the number of non-missing values that exist for each year and establishment and included this as an additional control in the regressions. Third, we dropped observations constructed from less than four full quarters. The results were quite robust across all three methods and the Tables report results based on the first method.

Fixed Asset Register (FAR). The FAR asks for the historic cost (gross book value) of the fixed assets held on the firms' asset register, broken down by the years of acquisition. The survey provides information on IT hardware assets only, and covers the years 1995 up to 2000. The survey provides information for about 1,000 hardware observations.

Annual Business Inquiry (ABI). The ABI contains a question on software expenditures from 2000 onwards. There are approximately 20,000 non-zero returned values for software investments in each year.

Estimation of IT capital stocks

We build stocks of IT capital applying the Perpetual Inventory Method (PIM) to the IT investment data (and the non-IT investment data) described above. The basic PIM equation is:

$$K_{it}^h = I_{it}^h + (1 - \delta^h) K_{it-1}^h \quad (B1)$$

where I_t^h represents real investment of asset type h (e.g. computer hardware, I_t^C) and δ_t^h is the asset specific depreciation rate. To construct real investment we deflate nominal investments using the economy-wide (asset specific) hedonic price indices for software and hardware

²² The extrapolation was done by simple averaging, but we also tried more sophisticated quarterly models taking into account the quarter surveyed. This made practically no difference.

provided by the NIESR (which are based on Jorgensen's US price deflators). We rebased to the year 2000 for consistency with the other PPI deflators (see below).

Estimation of TFP and capital services

To calculate the user cost (e.g. ρ^C is the rental price of IT capital) we use the Hall-Jorgensen formulation:

$$\rho_t^h = \frac{1 - A_t^h}{1 - T_t^h} [r_t + \delta_t^h - ((p_t^h - p_{t-1}^h) / p_{t-1}^h)] p_t^h \quad (\text{B2})$$

where ρ^h is the rental price of asset class h , r is the nominal interest rate, δ is the depreciation rate of the asset, and p^h is the asset price. The tax parameters are given by A which is the present-discounted value of depreciation allowances, and T which is the rate of corporate profits tax. We obtained user costs from the data underlying Oulton and Srinivasan (2004) kindly provided by the authors. These are economy wide

We can then calculate total profits as²³

$$\Pi_{it} = \sum_h \rho_t^h K_{it}^h \quad (\text{B3})$$

The share of each asset class in revenue is then

$$s_{it}^h = \frac{\rho_t^h K_{it}^h}{\sum_h \rho_t^h K_{it}^h} \frac{\sum_h \rho_t^h K_{it}^h}{pY} = \frac{\rho_t^h K_{it}^h}{\Pi_{it}} \frac{\Pi_{it}}{p_t Y_{it}} \quad (\text{B4})$$

that is used in calculating measured TFP in equation (7) and elsewhere.

Zeros

Both the BSCI and the QICE code missing values as zeros. While in the BSCI we are able to identify actual zero investments through a specific coding, for the QICE this is not possible. In the construction of the capital stocks we treated the zero investments observations as actual absence of IT investments. In the regressions we drop observations with zero IT capital stocks

Interpolations

In order to maximize the number of observations over which we could apply the PIM, we interpolated net investment observations for a single year of data if we observed investment the year before and the year afterwards. This affected only 2.8% of the observations in the regression sample and results are robust to dropping these observations.

Initial Conditions

²³ Note that empirically there are alternative ways to approach equation (B3). Our preferred method is to calculate

$$s_{it}^h = \frac{\rho_t^h K_{it}^h}{\Pi_{it}} \frac{\hat{\Pi}_{it}}{p_t Q_{it}} \text{ where } \Pi_{it} \text{ is taken from equation (B3) and } \hat{\Pi}_{it} \text{ is taken as the residual of revenues less}$$

materials and the wage bill.

In order to apply the PIM methodology, we need to approximate a starting value to start the recursion. We apply a similar methodology as the one devised by Martin (2005) to construct establishment level capital stocks in the ARD. For each firm, we first build two digit industry-specific IT Investment/Capital ratios using the NISEC02 industry level data-set provided by the NIESR, which contains separate time-series data on hardware and software capital stocks and runs up to 2001 (these are based on the input-output tables starting in 1975). We then use the ratio of the establishment's IT investment flow to the industry investment flow (denoted w_{it}^A for method "A") to impute the IT capital stock (i.e. we are assuming that the establishment's share of the IT capital stock in the industry is equal to the establishment's share of IT investment in the industry in the initial year). More precisely, we assume that for $t = 0$ only the initial plant level IT capital stock C_{i0}^A is:

$$C_{i0}^A = w_{it}^A C_{jt} \quad \forall i \in j; w_{it}^A = \left(\frac{I_{it}^C}{I_{jt}^C} \right)$$

where j represents an industry so a j sub-script represents an industry total – i.e. I_{jt}^C is total industry IT investment and C_{jt} is the total IT capital stock in time t . We apply this approximation to determine our initial condition in the first year that the establishment appears in our sample. For greenfield sites this is not an issue as their capital stock is zero. After the first year, we simply apply the PIM method.

Some of the establishments that we observe only for the first time may be investing systematically at a different rate from the industry average. To check whether our results were driven by the methodology used to build the initial conditions, we considered an alternative methodology based on employment weights (method "B"). For the first time we observed a plant in our sample we assumed that:

$$C_{i0}^B = w_{it-1}^B C_{jt-1} (1 - \delta) + I_{it}^C$$

$$w_{it-1}^B = \frac{L_{it-1}}{L_{j-1}} \quad \forall i \in j$$

So this is assuming that the establishment's share of the industry IT stock in the initial period is equal to the establishment's share of employment. Results are presented in Table A5 below and are consistent with the baseline method.

Depreciation

For all IT capital (software and hardware) we chose a depreciation rate of 36%. This choice is consistent with the analysis by methodology followed by the BEA which, in turn, derives from the study by Doms, Dunn, Oliner and Sichel (2004). In this study, the depreciation rate for PC's is estimated at approximately 50%, this value including both obsolescence and reevaluation effects. Since – as the BEA – we use real IT investments we have to use a lower depreciation rate to avoid double counting of the revaluation effect, included in the price deflators.

Basu et al (2003) argue that the true geometric rate of depreciation should be, in fact, approximately 30%. The significance and the magnitude of the coefficient obtained for both hardware and software are not affected by the exact choice of the alternative depreciation rate.

We also experimented with the extreme assumption of 100% depreciation rate for IT, thus working directly with the flows. Results are in Table A5 which shows a significant coefficient with a lower point estimate than in the main table (discussed below).

Across-Survey Stocks

Following the steps described above, we obtain hardware and software stocks within each different survey. We then matched our IT dataset with the ABI sample with non missing observations on other inputs and outputs (value added and gross output). In order to simplify the empirical analysis, we combined all the information of the different the surveys constructing overall across-surveys IT stocks for both hardware and software. Our strategy is to use the BSCI measure as the most reliable observation (as recommended by the data collectors). We then build our synthetic measure using the QICE stocks if the BSCI observation is missing or equal to zero and the QICE is different from zero. We finally use the FAR if both QICE and BSCI are missing and/or equal to zero and the FAR is not. For the software capital stock we also use the ABI information, following the same order described above. The sources of the aggregate capital stocks are summarized in the following table:

Source	Hardware Capital	Software Capital
BSCI	3,704	2,387
QICE	17,517	13,049
FAR	686	881
ABI	-	43,735

In order to keep track of the possible measurement error introduced using this procedure, we introduce in all the IT regressions a dummy that identifies the provenience of the observation for both the hardware and the software stocks. These dummies and their interactions with the IT coefficients are not significantly different from zero.

A small portion of the firms included in our dataset responded to more than one survey. We use some of this overlapping sample to get a better understanding of the measurement error in the data. By comparing the reports from the same establishments we calculate that there is much more measurement error for software than for hardware, which is why we currently focus on hardware. We did not find any evidence that the measurement error for hardware was greater for US firms than other firms, however, which is reassuring.

A3 OTHER DATA

PPI deflators

We deflate gross output using the PPI deflators 2000 based provided by the ONS. For the manufacturing sector, the deflators are usually available at the 4 SIC digits level (MM17 PPI deflators). Whenever this was not the case, we used a general deflator for the 2 digit industry

or a deflator relative to the overall manufacturing sector. For the service sector we used a set of experimental deflators generated by the ONS. These deflators refer to a limited number of 5 SIC digits industries. For all the other industries we use the general deflator for the overall service sector.

Skills

In our analysis we use industry and/or region and/or year specific skills measures built using the Labour Force Survey data set. Our preferred measure of skills is the proportion of people in the sample having as a highest qualification a degree or equivalent and/or a title defined as “higher education” by the standard LFS classifications (post GSE A levels), even though the results are not qualitatively different once we use only the proportion of people with a degree.

We use LFS data from 1993 to 2003. First, we keep only observations referring to people between 24 and 64 years. We drop observations for which no information is available on education. The cells over which the proportion is computed are defined by two digit industry, one digit region and year (we also considered four and three digit industry and area-only definitions). For each index, we drop observations that are based on less than 50 observations. We use the number of observations of the LFS cells as weights for the skills regressions. We also constructed similar datasets, containing information on education as well as wages and hours worked. These indexes are built only for observations having non-missing values for these additional variables.

Alternative IT measure from the E-Commerce Survey

The E-Commerce Survey asks a question to plant managers directly about how many workers use computers in the establishment. Although this is conceptually much cruder than the IT capital stock, it has the advantage that we do not have to rely so much on assumptions concerning the initial conditions. In Table 2 we discuss the results from this measure, showing very similar results to those obtained from using the IT capital measure.

A4 CLEANING

We used standard procedures to clean the ABI and the IT data. First, we dropped all observations with negative value added and/or capital stock. Secondly we dropped the top and bottom percentile of the distribution of $\frac{\Delta X}{X}$ for employment and gross value added. Thirdly, we dropped extreme values of total capital stock per employee and gross value added per employee. This step of the cleaning procedure was performed on the overall ARD sample.

We applied a similar cleaning procedure also to our across surveys IT variables. For hardware IT variables (investments and capital stocks) we dropped the top and bottom percentiles of the ratio of the variables on gross value added²⁴.

A5 DEFINITION OF I.T. INTENSIVE USING INDUSTRIES

²⁴ The results of the regression are qualitatively similar if the IT data are cleaned using the ratio investments or stocks per employee.

We focus on “IT intensive” sectors that are defined to be those that use IT intensively according to (Van Ark et al, 2002) who base their definitions on Stiroh (2002). The basic splits between industries that are intensive in “IT use” are based on the proportion of IT capital services in total capital services. This uses US data to calculate the service flows as these are more accurate than service flow calculations based on UK data. The industries are split based on the median proportion of IT capital service flows in total capital service flows.

The IT intensive using sectors are listed in Table A1. Note that the other “non-IT intensive” sectors include the sectors that produce IT intensively. We also considered these as a separate category but found in relation to their IT coefficients they were significantly different from the sectors that used IT intensively. All industries are based on ISIC Revision 3.

A6. TAKEOVERS

The identification of takeovers consists of three basic steps. First, for all the available years (1980-2003 for manufacturing and 1997-2003 for services) we combine all the raw ARD data relative to selected and non selected firms. We thus create a register file that allows us to keep track of the whole history of each firm, and exploit the uniqueness of the reporting unit reference number to correct for obvious reporting problems (i.e. firms that disappear in one year, and appear again after some time). Second, for each firm we keep track of changes in the foreign ownership information and the enterprise group reference number to identify foreign and domestic takeovers²⁵. Third, to control for measurement error in the takeover identification, we drop from the sample firms that are subject to more than three takeovers during their whole history and firms that experience consecutive takeovers within a three year time period.

A7 ADDITIONAL ECONOMETRIC RESULTS

Table A4 gives some additional production function results comparing alternative econometric techniques. These alternative methods attempt to control for endogeneity of the regressors in the presence of correlated unobserved heterogeneity (the within group estimates in the main text treat the inputs as strictly exogenous). The econometric methods are System GMM (GMM-SYS) of Blundell and Bond (2000) and the Olley Pakes (1996) method.

Column (1) of Table A4 presents the results without fixed effects, but all other columns control for fixed effects. Across all specifications, all the factor inputs, including IT capital are positive and significant. In column (1) the sum of the coefficients on the factor shares is 0.99, very close to constant returns to scale. Column (2) includes a full set of 11,000 establishment specific fixed effects. The coefficients all remain significant at conventional levels. The coefficient on IT capital falls from 0.04 to 0.03, the coefficient on materials falls from 0.54 to 0.47. By contrast the coefficient on non-IT capital increases from 0.12 to 0.16 and the coefficient on labor rises from 0.29 to 0.32. Compared to many other results in the micro

²⁵ Foreign takeovers are observed if a firm experiences a change in the foreign ownership marker. Domestic takeovers are observed if a UK firm changes its enterprise reference number. See Griffith et al (2002) for more details on the methodology.

production function literature²⁶ the results here are reasonably stable when including fixed effects²⁷.

To implement the GMM system estimates we need to condition on a sample where we have at least three continuous time series observations (the OLS estimates keep all observations, even if we only observe an establishment for a single period). Column (3) conditions on the same sub-sample that we will estimate our GMM results on and re-runs the within groups estimate of column (2). The estimates are stable even after throwing away about three quarters of the sample. Column (4) presents the equivalent specification using GMM-SYS. The absence of higher order serial correlation and the failure of the Hansen-Sargan test to reject are consistent with the hypothesis that the instruments are valid. The coefficients on materials and non-IT capital fall and the coefficients on labour and IT capital rise compared to column (3). Column (5) implements a general dynamic model including lags of all the independent variables and the dependent variable. We then impose the common factor (COMFAC) restrictions by minimum distance and present these restricted estimates in the final column (note that we cannot reject the COMFAC restrictions as indicated by the diagnostics at the base of column (6)). The coefficient on IT (and the other factors) remains positive and significant with a coefficient of about 0.04 (similar to OLS levels in fact). Finally, column (6) implements a version of the Olley Pakes method. Although all the variables are significant at conventional levels this produces the lowest coefficient on IT capital in Table A4: 0.02.

Table A5 presents some further results with different assumptions over building the IT capital stock. Column (1) is a baseline specification using the usual assumptions. In column (2) we use employment weights to impute the initial value of the IT capital stock instead of total investment. In column (3) we simply replace the log of the stock of IT with the log of the flow. The IT capital coefficient remains positive and significant in both of these experiments.

Table A6 presents some results from experiments that allow all the coefficients in the production function regressions to be different by ownership type and by whether the establishment is in the IT intensive sector or not. There are 6 separate regressions (3 ownership types by two broad sectors). At the base of the table we perform various tests of this more general model to the more restrictive regressions in the main paper. The F-test reveals that the US multinationals cannot be pooled with the other firms in the IT intensive sectors. In the non-IT intensive sectors, by contrast, the pooling restrictions are not rejected and US multinationals appear statistically similar to other establishments in the sample.

²⁶ Griliches and Mairesse (1997), Olley and Pakes (1996) or Levinsohn and Petrin (2003)

²⁷ The transformation of variables into deviations from the industry mean helps stability and it may be that there is much less measurement error in this mandatory establishment survey than the typical firm study using accounting data.

TABLE A1: BREAKDOWN OF INDUSTRIES

IT Intensive (Using Sectors)

IT-using manufacturing

18 Wearing apparel, dressing and dying of fur
22 Printing and publishing
29 Machinery and equipment
31, excl. 313 Electrical machinery and apparatus, excluding insulated wire
33, excl. 331 Precision and optical instruments, excluding IT instruments
351 Building and repairing of ships and boats
353 Aircraft and spacecraft
352+359 Railroad equipment and transport equipment
36-37 miscellaneous manufacturing and recycling

IT-using services

51 Wholesale trades
52 Retail trade
71 Renting of machinery and equipment
73 Research and development
741-743 Professional business services

Non- IT Intensive (Using Sectors)

Non-IT intensive manufacturing

15-16 Food drink and tobacco
17 Textiles
19 Leather and footwear
20 wood
21 pulp and paper
23 mineral oil refining, coke and nuclear
24 chemicals
25 rubber and plastics
26 non-metallic mineral products
27 basic metals
28 fabricated metal products
34 motor vehicles

Non-IT Services

50 sale, maintenance and repair of motor vehicles
55 hotels and catering
60 Inland transport
61 Water transport
62 Air transport
63 Supporting transport services, travel agencies

70 Real estate
749 Other business activities n.e.c.

Non-IT intensive other sectors

10-14 Mining and quarrying
50-41 Utilities
45 Construction

IT Producing manufacturing

30 Office Machinery
313 Insulated wire
321 Electronic valves and tubes
322 Telecom equipment
323 radio and TV receivers
331 scientific instruments

IT producing services

64 Communications
72 Computer services and related activity

Notes

These are taken from Van Ark et al (2002) following Stiroh (2002a). Not all industries are represented because the ABI does not cover the public sector (health, education and public administration) and the financial sector.

TABLE A2 - SUMMARY STATISTICS SAMPLE (2001 CROSS SECTION)**All Firms**

Variable	Frequency	Mean	Median	Standard Deviation
Employment	7495	795.91	238.00	3943.87
Gross Output	7495	84,475.46	20,053.00	445,039.30
Value Added	7495	28,440.95	6,765.64	167,510.40
Capital per worker	7495	84.03	46.97	112.70
Value Added per worker	7495	38.92	28.26	52.69
Gross Output per worker	7495	118.89	81.08	132.32
Total Materials per worker	7495	79.37	44.47	102.60
IT Capital/ Gross Output	7495	0.0103	0.0041	0.02
IT expenditure per worker	7495	0.39	0.14	0.87
IT capital	7495	989.65	76.55	10,548.86
Materials as a share of gross output	7495	0.57	0.59	0.24
Labor costs as a share of gross output	7495	0.32	0.28	0.22
ln(IT Capital)	7495	4.44	4.34	2.02

Notes: All monetary amounts are in sterling in year 2000 prices, deflated using ONS four SIC digit producer price indexes; firm level value added is constructed as the sum of turnover, variation of total stocks, work of capital nature by own staff, insurance claims received minus purchases; total stocks are constructed as described in the Appendix. All variables in units of 1000s except ratios and employment.

TABLE A3 - DESCRIPTIVE STATISTICS BROKEN DOWN BY MULTINATIONAL STATUS

Panel A Summary Statistics (all in deviations from SIC4 year mean)							
		Employment	Value added per Employee	Gross output per Employee	Capital per Employee	Materials per Employee	IT Capital per Employee
US Multinationals							
	Mean	148.29	123.56	123.20	127.12	123.54	144.26
	St. Deviation	238.77	122.52	101.75	124.89	118.41	196.77
	Observations	569	569	569	569	569	569
Other Multinationals							
	Mean	145.83	111.97	113.00	117.28	113.09	117.89
	St. Deviation	216.97	93.35	75.47	112.72	98.48	155.57
	Observations	2185	2185	2185	2185	2185	2185
UK domestic							
	Mean	73.08	91.66	91.22	88.78	91.14	86.44
	St. Deviation	121.59	97.95	96.68	120.19	122.82	177.78
	Observations	4741	4741	4741	4741	4741	4741

TABLE A4 –PRODUCTION FUNCTIONS: ALTERNATIVE ECONOMETRIC ESTIMATORS

Estimation Method	(1) OLS, No FE	(2) OLS, FE	(3) OLS, FE	(4) GMM- SYS, Static	(5) GMM-SYS, Dynamic (Unrestricted)	(6) GMM-SYS COMFAC (Restricted)	(7) OLLEY- PAKES
Dependent variable: ln(Gross Output)							
Ln(C_t) IT capital	0.0440*** (0.0023)	0.0299*** (0.0040)	0.0265*** (0.0063)	0.0391*** (0.0171)	0.0656* (0.0373)	0.0430** (0.0211)	0.0204*** (0.0030)
Ln(C_{t-1}) IT capital, lagged	-	-	-	-	-0.0343 (0.0242)	-	-
Ln(M_t) Materials	0.5384*** (0.0080)	0.4665*** (0.0193)	0.4702*** (0.0283)	0.3998*** (0.0402)	0.3293*** (0.0750)	0.3595*** (0.0494)	0.5562*** (0.0102)
Ln(M_{t-1}) Materials, lagged	-	-	-	-	-0.0715 (0.0534)	-	-
Ln(K_t) Non-IT Capital	0.1193*** (0.0063)	0.1650*** (0.0153)	0.1953*** (0.0234)	0.1584*** (0.0410)	0.3618*** (0.0869)	0.2937*** (0.0526)	0.1511*** (0.0115)
Ln(K_{t-1}) Non-IT Capital, lagged	-	-	-	-	-0.1815*** (0.0592)	-	-
Ln(L_t) Labour	0.2868*** (0.0062)	0.3177*** (0.0198)	0.2979*** (0.0209)	0.4158*** (0.0479)	0.2981*** (0.0829)	0.3524*** (0.0560)	0.2611*** (0.0080)
Ln(L_{t-1}) Labour, lagged	-	-	-	-	0.0091 (0.0624)	-	-
Ln(Y_{t-1}) Gross Output, lagged	-	-	-	-	0.2330*** (0.0581)	-	-
Rho, ρ	-	-	-	-	-	0.3488*** (0.0291)	-
Observations	22,736	22,736	6,763	6,763	6,763	6,763	12,069
Fixed effects	NO	YES	YES	YES	YES	YES	YES
1st order serial correlation test (p value)	-	-	-	-3.634 (0.000)	-5.223 (0.000)	-	-
2nd order serial correlation test (p value)	-	-	-	-0.239 (0.811)	0.953 (0.341)	-	-
Sargan-Hansen Test (p value)	-	-	-	34.38 (0.354)	24.65 (0.852)	-	-
COMFAC (p value)	-	-	-	-	-	6.7474 (0.1500)	-

NOTES: * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variable in all columns is the log of gross output. The time period is 1995-2003. All variables are expressed in deviations from the 4 digit industry mean in the same year. Firm level value added is constructed as the sum of turnover, variation of total stocks, work of capital nature by own staff, insurance claims received minus purchases; total and IT capital stocks are constructed using the perpetual inventory method as described in the text. The estimation method in columns (1) through (3) is OLS (with fixed effects in columns (2) and (3)); in columns (4) to (6) we use System-GMM (Blundell and Bond, 1998) and in column (7) we use Olley Pakes (1996). Standard errors in brackets under coefficients in all columns are clustered by establishment (i.e. robust to heteroskedacity and autocorrelation of unknown form). One step GMM results reported. All columns include age, foreign ownership and region dummies and a dummy taking value one if the firm belongs to a multi-firm enterprise group as additional controls. In columns (4) to (6) instruments are all plant level factor inputs lagged t-2 and before (when available) in the differenced equation (i.e. m_{t-2} , n_{t-2} , k_{t-2} , c_{t-2} , q_{t-2}) and lagged differences in the levels equation (Δm_{t-1} , Δn_{t-1} , Δk_{t-1} , Δc_{t-1}). Serial correlation tests are LM tests of the first differenced residuals (See Arellano and Bond, 1991). Sargan-Hansen Test of instrument validity is a test of the over-identification restrictions. Olley Pakes uses a fourth order series expansion to approximate the phi function. Standard errors in Olley-Pakes are block bootstrapped with 200 replications.

APPENDIX TABLE A5 - ALTERNATIVE ASSUMPTIONS ON I.T. CAPITAL STOCK CALCULATIONS

Dependent variable	(1)	(2)	(3)
Ln(M)	ln(GO)	ln(GO)	ln(GO)
Materials	0.4640*** (0.0215)	0.4657*** (0.0213)	0.4662*** (0.0215)
Ln(K)	ln(GO)	ln(GO)	ln(GO)
Non-IT Capital	0.1669*** (0.0181)	0.1516*** (0.0170)	0.1755*** (0.0185)
Ln(L)	ln(GO)	ln(GO)	ln(GO)
Labour	0.3183*** (0.0243)	0.3116*** (0.0238)	0.3277*** (0.0245)
Ln(C)	ln(GO)	ln(GO)	ln(GO)
hardware capital	0.0301*** (0.0045)	0.0595*** (0.0082)	-
Ln (I^C)	-	-	0.0115*** (0.0025)
IT Investment flow			
Firms	10,648	10,648	10,648
Observations	19,587	19,587	19,587
Adjusted R Squared	0.99	0.99	0.99
IT Measure	Standard	Employment Weights for initial conditions	Investment in IT (flow)
Sample	All Sectors	All Sectors	All Sectors
Fixed effects	YES	YES	YES

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variable in all columns is the log of gross output. The time period is 1995-2003. All variables are expressed in deviations from the 4 digit SIC mean in the same year. The estimation method in all columns is OLS. All columns include plant level fixed effects. Standard errors in brackets under coefficients in all columns are clustered by firm. Column (1) uses the preferred IT measure (investment weights), Column (2) uses the alternative IT measure (employment weights), Column (3) uses hardware investment flow.

TABLE A6 – ALLOWING ALL PRODUCTION FUNCTION COEFFICIENTS TO VARY BY OWNERSHIP STATUS

	Panel A: IT-Intensive Sectors			Panel B: Non IT-Intensive Sectors		
Dependent variable	(1)	(2)	(3)	(4)	(5)	(6)
Sample	ln(GO) US firms	ln(GO) All firms except US firms	ln(GO) All Multinationals Except USA	ln(GO) US firms	ln(GO) All firms except US firms	ln(GO) All Multinationals Except USA
Fixed effects	YES	YES	YES	YES	YES	YES
Ln(C) IT capital	0.0509*** (0.0165)	0.0271*** (0.0044)	0.0333*** (0.0071)	0.0308*** (0.0033)	0.0284*** (0.0050)	0.0324*** (0.0109)
Ln(M) Materials	0.5696*** (0.0361)	0.5463*** (0.0181)	0.5189*** (0.024)	0.4294*** (0.0174)	0.4479*** (0.0311)	0.4586*** (0.0429)
Ln(K) Non-IT Capital	0.0901** (0.0407)	0.1321*** (0.0136)	0.1161*** (0.0205)	0.1907*** (0.0144)	0.2011*** (0.0247)	0.2025*** (0.0538)
Ln(L) Labour	0.2533*** (0.0481)	0.2684*** (0.0193)	0.2939*** (0.0258)	0.3390*** (0.0169)	0.3247*** (0.0264)	0.3029*** (0.0706)
Establishments	416	3,829	1,373	7561	2599	537
Observations	767	7,138	2,600	14,831	5,393	1,025
Adjusted R Squared	0.91	0.94	0.95	0.9	0.91	0.91
F statistic of restrictions of coefficients across sub-samples (threshold at 1%=3.02, threshold at 5%=2.21, threshold at 10% level=1.84)						
H₀: Coefficients on US firms the same as coefficients on non-US firms;		F = 3.81			F = 1.50	
H₀: Coefficients on US firms the same as coefficients on other MNE's;		F = 3.27			F = 0.44	

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variable in all columns is the log of gross output. The time period is 1995-2003. All variables are expressed in deviations from the 4 digit SIC mean in the same year. The estimation method in all columns is OLS. All columns include plant level fixed effects. Standard errors in brackets under coefficients in all columns are clustered by firm (i.e. robust to heteroskedacity and autocorrelation of unknown form). See Table A1 for definition of IT using sectors.

APPENDIX B: ECONOMETRIC MODELS

B.1 BASIC APPROACH

Re-consider the basic production function in equation (1) suppressing the tildas for simplicity

$$q_{it} = a_{it} + \alpha_{it}^M m_{it} + \alpha_{it}^L l_{it} + \alpha_{it}^K k_{it} + \alpha_{it}^C c_{it} \quad (A1)$$

We can exploit the fact that we have panel data on our plants and attempt to control for unobserved heterogeneity more rigorously. We attempt to deal with the endogeneity of the time varying inputs (IT capital, non-IT capital, labour and materials) through various panel data techniques for production functions (specifically System GMM and versions of Olley Pakes, 1996).

B.2 SYSTEM GMM

The basic equation we wish to estimate can be written in simplified form as

$$y_{it} = \theta x_{it} + u_{it} \quad (A2)$$

Where θ is the parameter of interest. Assume that the stochastic error term, u_{it} , takes the form

$$\begin{aligned} u_{it} &= \eta_i + \tau_t + \omega_{it} \\ \omega_{it} &= \rho \omega_{it-1} + \nu_{it} \end{aligned} \quad (A3)$$

The τ_t represent macro-economic shocks captured by a series of time dummies, η_i is an individual effect, and ν_{it} is a serially uncorrelated mean zero error term. The other element of the error term, ω_{it} is allowed to have an AR(1) component (with coefficient ρ) which could be due to measurement error or slowly evolving technological change. Substituting (A3) into (A2) gives us the dynamic equation

$$y_{it} = \pi_1 y_{it-1} + \pi_2 x_{it} + \pi_3 x_{it-1} + \eta_i^* + \tau_t^* + \nu_{it} \quad (A4)$$

The common factor restriction (COMFAC) is $\pi_1 \pi_2 = -\pi_3$. Note that $\tau_t^* = \tau_t - \rho \tau_{t-1}$ and $\eta_i^* = (1-\rho)\eta_i$.

In the main results section we present several econometric estimates of production functions (OLS, within groups and GMM). Blundell and Bond (1998) recommend a system GMM approach to estimate equation (A4) and impose the COMFAC restrictions by minimum distance. If we allow inputs to be endogenous we will require instrumental variables. In the absence of any obvious natural experiments we consider moment conditions that will enable us to construct a GMM estimator for equation (A4). A common method would be to take first differences of (A4) to sweep out the fixed effects:

$$\Delta y_{it} = \pi_1 \Delta y_{it-1} + \pi_2 \Delta x_{it} + \pi_3 \Delta x_{it-1} + \Delta \tau_t + \Delta v_{it} \quad (\text{A5})$$

Since v_{it} is serially uncorrelated the moment condition

$$E(x_{it-2} \Delta v_{it}) = 0 \quad (\text{A6})$$

ensures that instruments dated $t-2$ and earlier²⁸ are valid and can be used to construct a GMM estimator for equation (4) in first differences (Arellano and Bond, 1991). A problem with this estimator is that variables with a high degree of persistence over time (such as capital) will have very low correlation between their first difference (Δx_{it}) and the lagged levels being used as an instrument (e.g. x_{it-2}). This problem of weak instruments can lead to substantial bias in finite samples. Blundell and Bond (1998) point out that under a restriction on the initial conditions another set of moment conditions are available²⁹:

$$E(\Delta x_{it-1} (\eta_i + v_{it})) = 0 \quad (\text{A7})$$

This implies that lags of the first differences of the endogenous variables can be used to instrument the levels equation (A4) directly. The econometric strategy is then to combine the instruments implied by the moment conditions (A6) and (A7). We stack the equations in differences and levels (i.e. (A4) and (A5)). We can obtain consistent estimates of the coefficients and use these to recover the underlying structural parameters in (A2).

The estimation strategy assumes the absence of serial correlation in the levels error terms (v_{it})³⁰. We report serial correlation tests in addition to the Sargan-Hansen test of the over-identifying restrictions in all the GMM results³¹.

This GMM “system” estimator has been found to perform well in Monte Carlo simulations and in the context of the estimation of production functions. The procedure should also be a way of controlling for transitory measurement error (the fixed effects control for permanent measurement error).

B.3 OLLEY PAKES

Reconsider the basic production function³²

$$q_{it} = \alpha^L l_{it} + \alpha^M m_{it} + \alpha^K k_{it} + \alpha^C c_{it} + \omega_{it} + \eta_{it} \quad (\text{A8})$$

²⁸ Additional instruments dated $t-3$, $t-4$, etc. become available as the panel progresses through time.

²⁹ The conditions are that the initial change in productivity is uncorrelated with the fixed effect $E(\Delta y_{i2} \eta_i) = 0$ and that initial changes in the endogenous variables are also uncorrelated with the fixed effect $E(\Delta x_{i2} \eta_i) = 0$

³⁰ If the process is MA(1) instead of MA(0) then the moment conditions in (A6) and (A7) no longer hold. Nevertheless $E(x_{it-3} \Delta v_{it}) = 0$ and $E(\Delta x_{it-2} (\eta_i + v_{it})) = 0$ remain valid so earlier dated lags could still be used as instruments. This is the situation empirically with the wage equations.

³¹ These are based on the first differenced residuals so we expect significant first order serial correlation but require zero second order serial correlation for the instruments to be valid. If there is significant second order correlation we need to drop the instruments back a further time period.

³² For notational simplicity we abstract from plant age, but this we consider this in the implement this in the estimation routine along the same lines as Olley and Pakes (1996).

The “efficiency term”, ω_{it} , is the unobserved productivity state that will be correlated with both output and the variable input decision and η_{it} is an i.i.d. error term (either measurement error or an unforecastable shock to productivity). We assume that both capital stocks are predetermined and current investment (which will react to productivity shocks) takes one period before it becomes productive, i.e. $I_{it}^K = I_{it-1}^K + (1 - \delta^K)K_{it-1}$ and $I_{it}^C = I_{it-1}^C + (1 - \delta^C)C_{it-1}$.

It can be shown that the investment policy functions for IT and non-IT are monotonic in non-IT capital, IT capital and the unobserved productivity state.

$$i_{it}^K = i^K(k_{it}, c_{it}, \omega_{it})$$

$$i_{it}^C = i^C(k_{it}, c_{it}, \omega_{it})$$

The investment policy rule can therefore be inverted to express ω_{it} as a function of investment and capital. We choose to focus on the non-IT investment policy function which is inverted to obtain the proxy:

$$\omega_t^K(i_{it}^K, k_{it}, c_{it})$$

The first stage of the OP algorithm uses this invertibility result to re-express the production function as:

$$y_{it} = \alpha^L l_{it} + \alpha^M m_{it} + \alpha^K k_{it} + \alpha^C c_{it} + \omega_t^K(i_{it}^K, k_{it}, c_{it}) + \eta_{it} = \alpha^L l_{it} + \alpha^M m_{it} + \phi(i_{it}^K, k_{it}, c_{it}) + \eta_{it}$$

$$\text{where } \phi(i_{it}^K, k_{it}, c_{it}) = \phi_t = \omega_t^K(i_{it}^K, k_{it}, c_{it}) + \alpha^K k_{it} + \alpha^C c_{it}$$

We approximate this function with a series estimator that previous applications have shown to be close to the fully non-parametric approximation. We can use this first stage results to get estimates of the coefficients on the variable inputs. The second stage of the OP algorithm is

$$y_{it}^* = y_{it} - \alpha^L l_{it} - \alpha^M m_{it} = \alpha^K k_{it} + \alpha^C c_{it} + \omega_{it} + \eta_{it}$$

Note that the expectation of productivity conditional on last period’s information set (denoted Ω_{t-1}) is

$$\omega_{it} | \chi_{it}=1 = E[\omega_{it} | \omega_{it-1}, \chi_{it} = 1] + \xi_{it}$$

where $\chi_{it} = 1$ indicates that the firm has chosen not to shut down (in the empirical results we experiment with also allowing for a selection stage over the decision to exit). This expression for the productivity state follows from the assumption that unobserved productivity evolves as a first order Markov process. Again we assume that we can approximate this relationship with a high order series approximation $g(\omega_{it-1})$.

Substituting this in to the “second stage” and taking expectations conditional on last period’s information set gives us

$$E(y_{it}^* | \Omega_{t-1}) = \alpha^K k_{it} + \alpha^C c_{it} + g[\phi(i_{it-1}^K, k_{it-1}, \alpha^C c_{it-1}) - \alpha^K k_{it-1} - \alpha^C c_{it-1}]$$

Since we already have in hand estimates of the ϕ_{t-1} function this amounts to estimating by Non-Linear Least Squares (NLLS). This now gives us all the relevant parameters of the production function.

There are numerous extensions to the basic Olley-Pakes methodology that have been suggested. One we considered was the additional selection correction originally suggested by the authors, but this made little difference to the results so the tables report the non-selectivity corrected results.